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Lead-Zinc Deposits

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# *THE LEAD- AND ZINC-DEPOSITS OF THE MISSISSIPPI VALLEY.*

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## INTRODUCTION.

AN investigation, conducted by the author, was begun in September, 1889, by the United States Geological Survey, having for its object the study of the questions bearing upon the occurrence and manner of formation of the deposits of lead- and zinc-ores in Missouri and the adjoining States. The field-work was completed in December, 1891. During the first season the State Geological Survey of Missouri furnished an assistant, and in other ways co-operated in the research within the boundaries of that State. In order that the ore-deposits of the southwest might be compared with those of other sections of the Mississippi valley, an examination was made of the lead- and zinc-mining area of Wisconsin-Iowa, and of the argentiferous lead-mines of the region extending westward from Hot Springs, Arkansas, to Indian Territory. In the discussion of the general geology, and in comparisons between the ore-deposits of the Mississippi valley and those of the Rocky Mountains, the writer has drawn largely from his personal experience, having been engaged for many years in professional work as a geologist and mining engineer in that region. The Director of the U. S. Geological Survey and the State Geologist of Missouri have kindly consented to the publication of the present paper.

While giving the more important economic results, an endeavor has been made to set forth the unity of plan which appears in the formation of the deposits of lead and zinc of the Mississippi basin, and to show their relation to the argentiferous ores of the Rocky Mountains—that the ores of gold, silver, and mercury, and also of copper, antimony, zinc, and lead, have a universal common origin, irrespective of the geological formations in which they occur.

## Location, Topography, and Structure of the Lead- and Zinc-Mining Regions of the Mississippi Valley.

The level surface of the country drained by the Mississippi river, lying between the Alleghanies and the plains along the eastern slope of the Rocky Mountains, is broken by a number of remarkable areas of uplift. At the north, stretching from the Great Lakes southerly, covering the State of Wisconsin and contiguous sections of Iowa and Illinois, occurs a vast promontory of land, described by Chamberlin under the title of the Wisconsin Island.*

In Ohio, Indiana, and central Kentucky is situated the Cincinnati anticlinal, made known by the labors of Newberry and later investigators. The elevated region of southern Missouri and northwestern Arkansas, reaching from the confluence of the Missouri and Mississippi rivers southwesterly to Indian Territory, has been named by Broadhead the Ozark uplift.†

The most southerly of these great areas of upheaval, designated by Branner as the Ouachita uplift, forms an easterly and westerly range, extending through central Arkansas and Indian Territory from the vicinity of Little Rock, Arkansas, nearly to the pan-handle of Texas.‡

The deposits of lead- and zinc-ores of the Mississippi valley are associated with certain of these uplifted areas. The lead-region of the upper Mississippi is located in the southern part of Wisconsin and adjoining portions of the States of Iowa and Illinois, in the southwestern section of the Wisconsin Island. The lead-mines of southeastern Missouri, and the deposits of lead and zinc of the southwestern part of the State and of the extension of that field into Kansas, Indian Territory, and northwestern Arkansas, are all included within the boundaries of the Ozark uplift. Quartz veins, carrying argentiferous galena associated with zinc-blende, occur at intervals in the Ouachita uplift from the region about Hot Springs and Little Rock, Arkansas, westward into Indian Territory.

The Cincinnati anticlinal is exceptional, and from some cause appears to be barren of deposits of lead- and zinc-ores. In Henry county, Kentucky, in the extension of this uplift, small deposits of

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* *Geol. Sur. of Wisconsin*, vol. i., T. C. Chamberlin.

† "The Geological History of the Ozark Uplift," by G. C. Broadhead, *Am. Geologist*, Jan., 1889.

‡ *Reports of the Arkansas Geol. Survey*, J. C. Branner.

lead-ore occur. Galena is also found in limited quantities, associated with fluorspar, in southern Illinois, in the vicinity of Rosiclare. These deposits have lately been investigated by S. F. Emmons, of the United States Geological Survey, and are made the subject of a paper in our *Transactions*.* This district extends across the Ohio river into the contiguous counties in Kentucky, and appears to form an outlier of the Ozark uplift.

*The Ozark Uplift.*—In outline rudely quadrilateral, this elevated region covers the southern half of Missouri and nearly all of that portion of Arkansas lying north of the Arkansas and directly west of the Black river, extending for a short distance over the contiguous corners of Indian Territory and Kansas, an aggregate area exceeding 50,000 square miles. The axis is approximately a line prolonged from the Mississippi river, at a point equidistant from St. Louis and Cairo, to Grand River, at the junction with Spavinaw creek, in the northeastern part of Indian Territory. The course of this axis is south 65° west; in this direction the extreme length of the Ozark uplift is nearly 320 miles, the breadth varying from 200 to 250 miles.

The structure is that of an elevated plateau, bounded by monoclinal folds; in the central area, the sedimental formations are nearly horizontal, dipping in the marginal belt, at gentle angles, away from the uplift, until the inclination of the strata is lost in the surrounding level country. In past geologic times, the Ozark area has, at several periods, formed an island in the ocean that extended over this portion of the Mississippi basin; now, it is circumscribed by rivers, conforming in their course to the palæo-littoral zone. On the northeast flank, the Missouri river flows in the monoclinal fold from Boonville, Missouri, to its junction with the Mississippi river; in the interval between St. Louis and Cairo, the Mississippi follows the general direction of this flanking fold, a small portion of the uplift lying on the east bank of the river in the State of Illinois. From the source, in southeastern Missouri, to its junction with White river in Arkansas, Black river conforms to the southeast marginal belt. On the south, the Ozark uplift is bounded by the valley of the Arkansas river, and on the extreme west by the Grand or Neosho river in Indian Territory and southeastern Kansas.†

The elevation of the Ozark uplift is from 400 to 2000 feet above

* Fluor-Spar Deposits of Southern Illinois," *Trans.*, xxi , 31.

† "The Geol. History of the Ozark Uplift," by G. C. Broadhead, *Am. Geologist*, January, 1889.

the sea; the central plateau, comprising the greater area of the upheaval, having an elevation of 900 to 1500 feet. No complete topographical survey of the region has been made; it is not probable, however, that any point attains an elevation exceeding 2100 feet. On many of the published maps of Missouri, the Ozark mountains are somewhat indefinitely marked, traversing the southern portion of the State. It is, perhaps, best that the designation of any portion of this elevated region as a mountain-range should be discontinued, for even the most hilly parts bear little resemblance to mountains, and would attract slight notice but for the contrast presented by the prevailing level surface of the Mississippi valley. The surface of southwest Missouri is gently rolling, with numerous high prairies and flat-topped divides. In the southern part of the State, and in northern Arkansas, the Ozark area is more hilly and broken. This topography has resulted from denudation by the present system of streams, modified somewhat by the character of the geological formations covering the surface. All the streams that drain the region are still corrading their beds, and, in the southwest, they have but little modified the plateau-character of the upheaval.

The sections of the Ozark area drained by the tributaries of the Arkansas and White rivers, are generally well timbered; the hills are covered with oak of good size, and the bottom-lands support a heavy growth of hickory, sycamore, and gum. In northern Arkansas, tracts of yellow pine (*pinus minis*) occur on the tops of the higher divides. The belt of high prairies extending from Springfield, Missouri, southwest to Galena, Kansas, is in most part destitute of trees, or, at best, supports a stunted growth of oak.

The mining-fields of the Ozark uplift, designated by Whitney as the lead-region of the Lower Mississippi,* comprise the lead-district of southeast Missouri and the lead- and zinc-fields of the southwest. The southeastern Missouri lead field is of limited extent, embracing portions of the counties of Jefferson, Washington, St. Francis, St. Genevieve, and Madison, covering an irregular area in the northeastern part of the Ozark upheaval. The lead- and zinc-mining district of the southwest covers that section of the country drained by the tributaries of the Missouri and Mississippi rivers where the States of Kansas, Missouri, and Arkansas, and the Indian Territory, corner nearly together.

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* *Report of the Upper Mississippi Lead-Region*, J. D. Whitney, 1862.

In Kansas, only the southeastern part of Cherokee county, the extreme southeastern corner of the State, belongs to this mineral area. In Missouri are included the counties of Jasper, Newton, McDonald, Barry, Lawrence, Dade, Stone, Taney, Christian, Douglas, Greene, Webster, Wright, Polk, Dallas, Camden, and Morgan, constituting the southwestern section of the State. In Arkansas, this mineral region covers the northwestern tier of counties, embracing Benton, Carroll, Madison, Boone, Newton, Marion, Searcy, Baxter, and Stone counties, with some outlying deposits in Lawrence county. The field also extends into the northeast part of Indian Territory, covering, in the Cherokee nation, the area included between the Grand or Neosho river and the west boundary of Missouri and Arkansas. The total area of the southwest mining region exceeds 20,000 square miles; the most productive section comprises Lawrence and Newton counties in Missouri, and Cherokee county in Kansas.

*The Ouachita Uplift.*—This closely-associated upheaval has been investigated only in the eastern part, within the boundaries of the State of Arkansas; its great extension in Indian Territory is comparatively unknown and unprospected. Commencing in the vicinity of Little Rock, Arkansas, it stretches, with a generally westerly course, through the central part of the State, and across Indian Territory, terminating before reaching the pan-handle of Texas. The extreme length of the range is nearly 450 miles; it forms a comparatively narrow belt. averaging, in the Arkansas section, a breadth of from 40 to 60 miles.

In structure, the Ouachita uplift differs from all the other upheavals in the area drained by the Mississippi river, and resembles in miniature a strongly-folded mountain-range. The Wisconsin, Cincinnati and Ozark uplifts are more in the nature of elevated plateaus of the Uinta type of Powell. The Ouachita uplift is not composed of a single flat-topped arch, but of a number of parallel anticlinal ridges and synclinal troughs sharply folded, the folds corresponding in direction with the general course of the range. This folding of the strata is so great throughout central-western Arkansas that the sedimentary rocks usually occur set on edge or dipping in steep angles, in strong contrast with the horizontal position of the strata in the Ozark uplift. This difference in the structure of the Ozark and Ouachita uplifts becomes the more notable from the narrow interval of separation; a narrow trough filled with the Coal-Measures and now occupied by the valley of the Arkansas,

having a width of from 30 to 50 miles, divides these two great uplifts. Contrasted with the Ozark area, the Ouachita uplift is characterized by a much more hilly and mountainous topography and a greater elevation, the higher peaks attaining an altitude of 2500 to 2850 feet above the sea.

Central Arkansas is well timbered, especially in the western part, in the section adjoining Indian territory. The ridges are covered with a heavy growth of oak and yellow pine. Along the river-bottoms, white oak, hickory, black walnut, gum and sycamore attain a very large size.

Deposits of silver-, lead- and zinc-ores are found grouped in small mining-districts irregularly scattered through the extent of the Ouachita uplift in Arkansas. In the continuation of this range in Indian Territory, ores of silver, lead, zinc and gold are known to occur at a number of localities, but owing to the reservation of vast tracts for the use of various Indian tribes and to the general unsettled condition of the country, the mineral wealth remains undeveloped.

*The Wisconsin Uplift.*—Of the great area included in the Wisconsin Island, it is necessary to consider here only the lead-region situated in the southwestern part, comprising the northeast portion of Iowa, bordering on the Mississippi river, the extreme northwestern corner of Illinois, and a large section in southwest Wisconsin. The region of the productive mines covers a tract nearly circular in outline, and from 60 to 80 miles in diameter; its total area within the three States is 3000 square miles.

In the southwest section of the Wisconsin uplift, the bedding of the strata is nearly horizontal, with a slight prevailing dip to the southwest. The lead-region lies from 580 to 1300 feet above the sea, the higher mounds reaching an altitude of 1000 to 1700 feet. The surface is that of a gently undulating plain, which results from the wide-spread erosion-carving of the horizontally-bedded rocks. Prominent features in the topography of the mining region are the conical and flat-topped mounds that rise above the general surface to an altitude of 100 to 400 feet, as remnants left by the denudation of the sedimentary formations which once extended in an unbroken sheet over the area. Extensive tracts in the lead-region are treeless, though some timber of value is found in the valleys and on the bottom-lands of the streams.

The central and northern sections of the Wisconsin uplift, beyond the limits of the mining region, are more elevated and exceedingly

rough and broken in surface, comparable to the mountainous districts of the Ouachita and Ozark upheavals.

## General Geology of the Areas of Uplift of the Mississippi Valley.

The lead- and zinc-mining regions are closely related in their local geology to that of the uplifts in which they occur. Viewed in its broader and more general relations, the geology is that of the Mississippi valley, modified, it is true, by peculiar conditions that have locally supervened, but forming a part of the great geologic domain which extends from the Alleghanies to the Rocky Mountains. The Ozark and Wisconsin uplifts date back to the Archæan age, when they formed a portion of the earliest land of North America, contemporary with the Labrador Continent, the Allegheny Mountains and the Black Hills of Dakota, and other outlying islands and spurs of the Rocky Mountain chain. A more recent origin has been attributed to the Ouachita uplift and the Cincinnati anticlinal: the oldest strata exposed to view are of Lower Silurian age. Possibly, these upheavals may have begun with disturbances reaching back into Archæan time, it being a general law, that disturbed areas have been subjected to recurrent periods of dynamic action from the most remote geologic eras.

*The Ozark Uplift.*—The more important events in the geological history of the Ozark area, having a bearing upon the occurrence of the ore-deposits, may be briefly sketched. The Archæan rocks were covered by the advancing ocean in the later Cambrian age; during the long interval between the Cambrian and the close of the Subcarboniferous period, the area of the Ozark uplift was an island or a group of islands, possibly completely submerged at times beneath the sea. With the opening of the Coal-period, the Ouachita, Ozark and Wisconsin islands were united by the elevation of the ocean-floor and formed a part of the continental area extending from northern Canada to the Gulf States, and from the eastern slope of the Allegheniés to Kansas and Indian Territory. Encircling marshes of the Coal-period surrounded the Ozark area, the southeast shore alone bordering on the Gulf of Mexico.

From the Carboniferous period to the present day, this continental area has been above the sea, so that Mesozoic and Cenozoic times are not represented in the Ozark uplift by any formations of marine origin. The deposits of the Glacial period and the Drift appear to have

reached their southern limit near the Missouri river and not to have extended over the Ozark uplift.

Throughout the great central area of the Ozark uplift, the Palæozoic strata are nearly horizontal, having been elevated without any considerable disturbance in the bedding. Along the marginal zone, the sedimentary strata form a gentle monoclinal fold, and dip radially away from the central elevated plateau. The movement of elevation has been accompanied, especially in southwestern Missouri and southeastern Kansas, by local faulting of the beds in this marginal area; the more pronounced faults formed at that time being either parallel to the axis, or tangential to the flanks of the uplift. Many examples of this form of upheaval occur in the plateau-regions of the Rocky Mountains, characterized by a central elevated plateau, or flat-topped arch, bordered by monoclinal folds along the flanks; the marginal folds becoming faults which dislocated the beds, where the simple flexure of the strata was inadequate to compensate the extent of the vertical movement. The effect of the Ozark uplift is seen in the disturbance of the rocks throughout eastern Kansas, where the formations have a general northwest dip away from the upraised area. In the northern counties of Arkansas, a general southerly and southwesterly dip of the strata is observed, approximately normal to the marginal belt of the Ozark uplift in that section.

Different geological formations are productive of lead and zinc in the several districts in the Ozark area. In southeastern Missouri the great lead-mines of Bonne Terre and Mine la Motte occur in Cambrian limestone. In the same regions the Lower Magnesian limestones of Calciferous age have contained deposits of lead- and zinc-ores which have yielded heavily in the past. The zinc-mines of Northern Arkansas, in the southern part of the Ozark uplift, also occur in the Lower Magnesian limestone. The upper beds of the Subcarboniferous formation, designated as the Cherokee limestone and Seneca chert, carry the large deposits of lead- and zinc-ores in the southwest. In the area covered by the Subcarboniferous rocks, are situated the mining-camps of Aurora, Webb City, Granby and Joplin in southwest Missouri, and Galena in Cherokee county, Kansas.

*The Ouachita Uplift.*—Before discussing the closely-contiguous Ouachita uplift, it should be noted that many errors occur in the older published statements of the geology of the central Arkansas region. Owen regarded the granitic outbursts in the vicinity of Little Rock and Magnet Cove, Arkansas, as of Archæan age, forming

outliers of the granitic region of southeastern Missouri. Dr. J. C. Branner has shown that these rocks are of eruptive origin, certainly later than the close of the Carboniferous, and possibly even as recent in intrusion as post-Cretaceous or early Tertiary. Dikes of igneous rock (peridotite) are described by Dr. Branner in Pike county, Arkansas, on the southern flank of the Ouachita uplift, intruded through beds of Cretaceous age.*

The Archæan granites and porphyries of southeastern Missouri extend within forty-five miles of the Arkansas-Missouri boundary, and an out-lying granitic mass appears on Spavinaw Creek in Indian Territory, about thirty-five miles from the Arkansas line; other and similar outliers of the Archæan rock are exposed at various points in Indian Territory and Texas. No occurrence of rocks of Archæan age has been found anywhere within the State of Arkansas.

The marked contrast of the complex structure of the Ouachita uplift with the simple formations of the other areas of upheaval in the Mississippi valley has been noted. This narrow belt of rough and hilly country, stretching from central Arkansas westerly to Texas, bears many points of resemblance in structure to some of the greater mountain-ranges. A series of sharply compressed anticlinal folds, heavily denuded, expose the strata upturned on edge in parallel ridges, having a general east and west trend. The plication of the beds involves the whole series of Palæozoic rocks, many thousand feet thick. No less distinct are the geological formations of this belt from those of other sections of the Mississippi valley; the rocks of this highly disturbed region are greatly metamorphosed, and the sediments from which certain of the beds have been formed appear to have differed in character and chemical composition at the time of their deposition. The prevailing formations of the Ouachita uplift are metamorphosed shales and quartzites, with novaculites—peculiar flint-like rocks occurring in massive strata and composed of nearly pure silica. These novaculites, though much older, are closely related in composition, and probably in origin, to the great chert-beds of the Subcarboniferous formations of the Ozark region.

The age of the geological formations included in the Ouachita uplift has been but imperfectly determined. Strata of limestone and shale, carrying fossils of Trenton age, have been identified near the middle of the exposed series of rocks; and a few species of graptolite recognized as Calciferous forms have been found in the slates as-

* *Annual Report, Geol. Sur.*, Arkansas, 1890, vol. ii., p. 377.

sociated with the novaculites. Along the northern flank of this uplift the rocks of the Coal-Measures are upturned by the movement effecting the elevation; the southern littoral belt is formed by Cretaceous limestones resting uncomformably on the denuded and folded strata of the Palæozoic rocks. Evidences of uncomformity were observed by the writer between the Trenton formation and the underlying novaculites, and also between these novaculites and still older quartzites and schists; so that it is not improbable that the exposed section may reach back to the earliest Silurian, possibly to the Cambrian, though no palæontological evidence has been obtained from these older rocks whereby their age could be determined.

It is difficult to correlate the formations of the Ouachita and Ozark uplifts, although the interval of separation is so small. This correlation becomes the more difficult, not only from the metamorphism of the rocks but from the general absence of fossils in the Palæozoic strata of the Ouachita area. The Archæan granites of the Ozark region are not represented in the Ouachita uplift; the older quartzites and shales at Hot Springs, Arkansas, may possibly be of Cambrian age, but bear little resemblance to the limestones and sandstones of that horizon occurring in southeast Missouri. The great magnesian limestones, regarded as Calciferous in age, which extend over so large an area in southern Missouri and northern Arkansas, with a thickness of 2000 to 3000 feet, have not been recognized in the Ouachita uplift, although the exposures of these rocks in the northern part of the State, included in the Ozark area, are separated from this uplift simply by the valley of the Arkansas river with its narrow belt of Coal-Measures. It is not until the Trenton limestones are reached that any correlation can be made; limestones of this age having been recognized by Prof. H. S. Williams in tne vicinity of Batesville, Arkansas, and at other points near the Mississippi river in the littoral belt of the Ozark uplift. No rocks of Devonian age have been found in this section; and the great Subcarboniferous formations of Missouri, embracing the limestones of the Chouteau, Burlington, St. Louis and Chester epochs, aggregating more than 600 feet in thickness, if represented at all in the Ouachita uplift, occur as coarse sandstones nearly barren of fossils.

Fissure-veins having a quartz gangue and carrying argentiferous lead-ores associated with ores of zinc, and in some instances of antimony, occur at intervals in the Ouachita uplift, in thevicinity of Little Rock and westward to Indian Territory. These veins traverse clay-slates and quartzites, probably of Calciferous or Trenton age.

*The Wisconsin Uplift.*—More closely, apparently, is the geology of the Wisconsin Island related to that of the Ozark uplift. Of similar structure and formation, each of these insular areas began in later Cambrian time with a nucleus of Archæan rocks, gradually extending in area by the deposition of broad littoral belts of Palæozoic sediments; the greatest growth taking place in westerly and southerly directions.* The geological formations of the Wisconsin uplift are capable of a more or less perfect correlation with those of the Ozark region; when compared, however, with respect to the occurrence of the ores of lead and zinc, it is seen that the special geological formations that are ore-bearing in a marked degree in either of these insular elevations are barren in the other, or carry but small deposits.

The magnesian limestones (Calciferous ?), in the Wisconsin–Iowa region are known to carry lead-ores in a few localities; while in Missouri and Arkansas, over a vast area of limestones of this age, numerous deposits both of lead and zinc occur. The principal ore-bearing formation of Wisconsin-Iowa, the Trenton limestone, covers a large section in the southwest part of the Wisconsin Island, but occurs in the Ozark uplift only in comparatively limited areas along the east and southeast marginal belt, and is not known to carry ores of lead and zinc. The Subcarboniferous limestones which form the productive ore-horizon in the mines of southwest Missouri do not occur anywhere in the elevated region of Wisconsin. Limestones of this age cover an extensive area in central Illinois, extending into northeastern Missouri and southeastern Iowa, in the broad interval between the Ozark and Wisconsin elevations, but they appear to be everywhere barren.

A long promontory of Archæan rocks stretches southwestward from the Canadian territory, north of Lake Superior, nearly across the state of Minnesota; and in Silurian time it became united to the Wisconsin uplift. This region forms a connection between the geologic province of the Great Lakes and that of the Mississippi valley. Nearly three hundred miles from the lead-region, on the opposite shore of the Wisconsin Island, occur the mines of native copper of the Upper Peninsula of Michigan with the associated intrusive rocks.

A large section of the Wisconsin uplift, including the lead-region, has never been covered by the ice of the Glacial period or by the de-

* *Geol. Sur., Wisconsin,* vol. i.

posits of the Drift, though entirely surrounded by glaciers and by the great sheet of Drift spreading over the Upper Mississippi valley. This driftless area has been investigated by Chamberlin and Salisbury, who, beides other causes, topographic and climatic, ascribe the exemption of this track from all glaciation to the diversion of the glaciers by highlands on the north.*

The region covered by the Cincinnati anticlinal, or uplift, in Ohio, Indiana and Kentucky was not visited, as the deposits of lead- and zinc-ores associated with this upheaval are small and are not worked at the present time. The structure of the Cincinnati axis is that of a broad and extremely flat-topped arch, the elevation being accompanied by comparatively little disturbance of the strata. This uplift is probably more recent in formation than the other elevated areas in the Mississippi valley; the oldest rocks exposed are of Trenton age, the region having become dry land at the close of the Lower Silurian.† Although, from their character and chemical composition, the rocks that cover this area would be looked upon as favorable ore-horizons, no considerable deposits of lead or zinc have been found anywhere within the limits of the elevation. The scattered occurences of lead-ores in the southern extension of the Cincinnati anticlinal into Kentucky are small and usually unworkable. The Drift in Ohio and Indiana reached its extreme southern limits near the Ohio river, covering all the Cincinnati uplift, with the exception of the area in the State of Kentucky.

*The Relation of these Areas of Uplifts to the Rocky Mountains.*—There is a marked parallelism between the early geological history af the Ozark and Wisconsin uplifts and that of the Black Hills of Dakota, the hilly region west of Fort Laramie, in Wyoming, and other outliers of the eastern slope of the Rocky Mountains, in that the Cambrian formation rests upon the denuded edges of the upturned metamorphic Archæan strata, and is overlaid by the Calciferous rocks. The Upper Silurian and Devonian rocks are either of local occurrence or are altogether wanting, and the Subcarboniferous limestones are deposited unconformably upon the older Palæozoic beds.

A similar section was described by the writer as occurring in the Organ Mountains in western Texas, where, in an ascending order,

* "The Driftless Area of the Upper Mississippi," by T. C. Chamberlin and R. D. Salisbury.—*Ann. Report U. S. Geol. Survey*, vol. vi.

† "The Trenton Limestone as a Source of Petroleum and Natural Gas in Ohio and Indiana," by Edward Orton.—*Ann. Report U. S. Geol. Survey*, vol. viii., p. 574.

the exposed strata are Archæan granite and Cambrian quartzite, succeeded by limestone of Calciferous and Trenton age, overlaid unconformably with massive limestones of the Carboniferous.* At the opening of the Carboniferous the parallelism fails; for the Rocky Mountain region remained an open ocean, depositing limestones of great thickness, while the Mississippi basin was elevated above the sea, and deposits of coal were formed in it where local conditions were favorable. The greater portion of the Rocky Mountain range did not emerge from the ocean until the close of the Cretaceous, when it became a part of the continental area.

The general resemblance in formation and in the succession of the associated sedimentary rocks in these elevated areas, from the Black Hills, along the line of outlying islands and spurs of the eastern border of the Rocky Mountain system, to the Mexican boundary, and from the Great Lakes through the Wisconsin, Ozark and Ouachita uplifts to central Texas, is evidence of a uniformity of origin, a correspondence in the dynamic movements which have taken place, and a relation that has been maintained with regard to the general prevalence of the ocean and to the deposition of the sedimentary strata over this extensive region, from Archæan to Carboniferous time.

## Dynamic Geology of the Areas of Uplift, Considered with Reference to the Formation of the Ore-Deposits.

The location of the deposits of lead and zinc, the origin of the mineral-depositing solutions, the means by which these solutions have been introduced into the strata, and the formation and occurrence of the ores all appear, upon examination, to be dependent upon the dynamic disturbances which have taken place in the past geologic history of these elevated sections of the Mississippi valley. The deposition of the ores of lead and zinc in the Ozark area and Wisconsin uplift has not been accompanied by igneous disturbances or by intrusions of igneous rocks within the mining-areas. This is the more remarkable, as the deposits of nearly all the mining-regions of the globe conform to the law announced by Humboldt, "*That the deposits of the precious metals and of lead, zinc and mercury, are usually associated with intrusions of igneous rocks.*" The igneous

* "Notes on the Geology of Western Texas,"—W. P. Jenney, *Am. Jour. Sci.*, 3d ser., vol. viii., p. 25.

rocks of the Archæan area of southeastern Missouri, included within the Ozark uplift, are far older than the earliest sedimentary deposits of lead- and zinc-ores. The eruptive rocks of the northern shore of the Wisconsin Island, in Upper Michigan, are all regarded by Van Hise as pre-Cambrian,* and therefore cannot have influenced the formation of the deposits of lead and zinc in the Palæozoic rocks of the southern part of the uplift. The presence of igneous rocks and of numerous evidences of intense igneous action in the Ouachita uplift and the relation of that upheaval to the Ozark area have been noted.

The more pronounced dynamic disturbances appear to have taken place at two distinct periods: the earlier, accompanying the continental elevation which involved all this portion of the Mississippi basin, occurring at the close of the Subcarboniferous period; and the later one in post-Cretaceous and early Tertiary time, culminating in the elevation of the Rocky Mountains, and characterized by widely extended outbursts of eruptive rocks and by igneous actions that seem to have been the direct cause of the fissuring and faulting of the strata and the formation of the ore-deposits.†

The result of this investigation of the deposits of lead and zinc in the Mississippi valley has made it possible to announce the general law that *all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore.*

While it is true that the ore-deposits are thus associated with areas of disturbance and fissures faulting the strata, so that it may be said that no ore-deposit occurs without a crevice or fissure in the rocks through which the ore-depositing solutions were introduced, it by no means follows that all fissures, even though they fault the rocks, are connected with the ore-deposits. In the barren sections of the mining districts many disturbed areas occur where no action of ore-deposition appears to have taken place, and this is equally true of mining regions in other parts of the world.

For the occurrence of ore-deposits, it is requisite, not only that the strata should be disturbed and faulted, but that the fissures should penetrate to and form open channels connecting with the zone of supply of the ore-forming solutions, which may be located at a consider-

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* *Journ. of Geol.*, vol. i., 1893.

† For the discussion of this subject see the section on "The Time at which the Formation of the Ore-Deposits Occurred."

able depth in the earth; also that the pressure should be sufficientto force the mineralizing solutions to the surface; that the solutions should contain metallic substances in adequate quantity, and that the physical and chemical conditions should be such as to permit ore-deposition. Through the absence of any of these conditions, districts otherwise favorable for ore may remain unmineralized.

*The Ore-Bearing Fissures.*—There are many evidences which cannot be set forth in detail, that the fissures associated with the ore-bodies have furnished the channels through which the mineral-depositing solutions were introduced. Among such evidences are: that the mineralizing action is often seen to have been diminished as the distance from the fissures increased; hard, impervious bars of rock have acted as dams to the solutions, causing certain areas of otherwise favorable rock to remain unimpregnated and barren; the minerals also are frequently observed to have been deposited first, near the walls and in the outer or lower parts of the ore-bodies, while the minerals of later formation occupy the central and upper parts of the deposits. The master-system of fissures is frequently traversed by a belt of parallel cross-fissures; and at such crossings or intersections, the richest and largest deposits of ore are frequently located, a result due to the cross-fissures aiding to keep open the channels through which the mineral-depositing solutions entered, and more completely shattering and brecciating the beds, thus affording free circulation for the solutions.

No general law is apparent with respect to the course of the ore-bearing fissures in the Southwest, though a tendency is noted in a number of districts for the fissures to form in systems that are either parallel to the axis of the Ozark uplift (N. 60° to 80° E.) or rudely parallel to the marginal belt in that special section. In the vicinity of Joplin, Missouri, the course of the more prominent fissures is usually included between N. 30° W. and N. 30° E. At Aurora, Missouri, the belts of fissures have courses N. 20° E. to N. 30° E., and E. and W. The course of the fissures seems to have had but little influence in the mines of the Southwest upon the character or size of the ore-deposits. Locally the belts of ore-bearing crevices having a given course may be the more productive; but in other districts the rule will not be found to hold good. In the Wisconsin-Iowa mining region the productive crevices have a general E. and W. course: the N. and S. systems are unmineralized, or carry ore-bodies of small size only.

The fissures through which the ore-depositing solutions appear

to have been introduced are usually nearly vertical, rarely dipping at angles of less than 60 degrees; and they vary from a narrow faulting-seam less than an inch wide (the smooth and often polished rock-surfaces of the faulting-plane being, in places, in close contact) to prominent crevices measuring 2 to 5 feet between the walls, filled with angular breccia formed by the attrition of the cheeks of the fissure moving upon one another. The brecciated material filling the fissure is often observed to have been more or less altered and mineralized by the waters traversing the crevice; and the included rock-fragments are, in some instances, silicified. Longitudinally, the fissures have an extent which, in most localities, cannot be determined; the underground workings of the mines seldom permit the inspection of more than a few hundred feet along the course of the main belt of fissures. At the lead-mines of Bonne Terre, in south-eastern Missouri, the stopes of the mine follow a strong belt of parallel fissures for 3000 feet; and at Mine La Motte, the master faulting-fissure is opened at points along its strike for a still greater distance.

In some localities, the fissuring of the strata has been accompanied by only a slight displacement of the rocks, notwithstanding which, the associated ore-deposits are large. The greatest vertical displacement of the strata, by faulting-movements, in the southwest region, occurs in Cherokee county, Kansas, in the area covered by the Cherokee limestone, where the fissures that traverse the ore-deposits are observed to cause a vertical displacement of the strata of a few inches up to 3 or 4 feet, and the combined faulting-movements, due to certain belts of parallel fissures, give aggregate vertical throws of 40 to 100 feet. In that locality, broad reefs or belts of chert, impressed by the movements of faulting, with a vertical, tabular, sheeted structure, course through the region, often traced by outcrops for a distance of one or two miles. These chert-belts have been brecciated and recemented by silicification into a very hard rock, which resists denudation, so that, by the erosion of the surrounding beds, they have been left projecting above the surface, resembling, to some extent, the outcrops of mineral-bearing quartz-veins in other mining countries—a resemblance which is increased by the occurrence of bunches of oxidized lead- and zinc-ores in these belts of brecciated chert. At intervals, along their course, the chert-outcrops overlie and cap extensive deposits of zinc-ore, occurring in zones of brecciation in the Cherokee beds beneath; and they should be regarded as the most favorable surface-indications for the occurrence of ore.

The evidence of faulting and fissuring of the strata in other camps in the Southwest is usually strongly marked. Though the vertical movements of the beds are often slight, the crushing and displacement of the strata, and the grooved, striated, and polished surfaces of the rocks, show that faulting has occurred.

In the zinc-mines of Marion county, Arkansas, the fissures traverse all the geological formations from the Third Magnesian limestone to the Subcarboniferous, through a vertical range of 500 to 600 feet; the vertical displacement of the strata by the ore-bearing fissures is from 5 to 25 feet.

There are evidences that the larger and more prominent fissures have a great extension in depth, and penetrate the Archæan floor on which the sedimentary formations rest. At Mine La Motte, the courses of the crevices in the granitic ridges are rudely parallel to the master-fissures in the underground workings of the mine. The Cambrian limestone and sandstones at this locality are probably nowhere over 400 feet thick; the vertical displacement of these beds by the master-fissure and its branches aggregate not less than 100 feet—a displacement in such massive strata which it is difficult to conceive to have taken place except as caused by a faulting movement so profound that the fissure must of necessity penetrate deep into the underlying Archæan. In general, throughout southern Missouri and northern Arkansas, the fissures associated with the ore-deposits appear to be best defined in depth, whereas in the surface-formations they appear to be split up into numerous branching crevices and fracture-planes.

In conclusion, it may be said of the fissures which occur in direct association with the deposits of lead- and zinc-ores in the Ozark and Wisconsin uplifts, that they are not the result of local causes, and are not confined to a narrow vertical range, or to rocks of a similar lithological character, but, on the contrary, that these fissures are the result of forces connected with wide-spread dynamic disturbances, affecting the North American continent, and that the fissures are faulting-planes of indefinite vertical extent, traversing all the geological formations from the crystalline rocks to the Coal-Measures.

## Occurrence of Lead- and Zinc-Ores in the Ozark Uplift.

*Ore-Bearing Formations.*—Some geological formations appear to be everywhere barren of ore; others occasionally carry small deposits, which form workable mines where the conditions are excep-

tionally favorable. The greater part of the lead-ore now produced in the Ozark uplift is mined from a single formation in southeastern Missouri, the lead-bearing Cambrian limestones of Bonne Terre and Mine La Motte; while nearly all the zinc-ore of the Southwest is yielded by the Cherokee limestone of Subcarboniferous age. Deposits of zinc- and lead-ores occur, indeed, in magnesian limestones of the Lower Silurian in central and southeastern Missouri and northern Arkansas, and formerly yielded the larger proportion of the product of that region; but most of the mines in the Lower Silurian limestones have been worked out, so that at present the yield is small compared with that of the other producing horizons. Local deposits of the ores of lead and zinc are found in the Devonian limestone and in beds of the Chouteau and Burlington epochs of the Subcarboniferous; but the relative yield from these formations is likewise small. The shales of the outlying coal-basins of Carboniferous age carry workable deposits of galena in Jasper county, Missouri. In Moniteau county, Missouri, the coal of these basins is intersected by thin seams of galena and zinc-blende, filling joints in the mass of the coal; in mining the coal these thin sheets of ore are separated and saved, thus affording an occasional shipment of ore.

The relative importance of the different geological formations is shown by their production. The total product of lead-ore of the Ozark area, for the year ending December 1, 1889, was 54,500 tons. Of this, 30,000 tons, or 55 per cent., was produced from the mines in the Cambrian limestones. Of a total production of 122,500 tons of zinc-ore for the same calendar year, 119,000 tons, or 97 per cent., was derived from the deposits in the Cherokee limestone, and in addition, 13,500 tons of lead-ore, or 21 per cent. of the total production, was extracted from the same formation.

*Ore-Horizons.*—In those geological formations in which workable bodies of ore occur, certain beds appear to have been peculiarly favorable to the deposition of the ore. The strata immediately above and below the ore-bearing beds are usually barren, or carry only small deposits. This characteristic of productive strata separated by barren beds is found, in many districts, to be uniform over large areas. The favorable strata are designated as ore-horizons and may be of any thickness, limited only by the occurrence of beds of uniform character and composition. They are from 3 to 15 feet thick in the zinc-mines of northern Arkansas, and from 40 to 80 feet thick at Webb City and Joplin in Jasper county, Missouri; and they extend through-

out all the beds of the lead-bearing limestone at Bonne Terre in the southeastern part of the State, attaining there a thickness of not less than 220 feet.

In relative order of importance the productive strata are, first, limestones, including both pure lime carbonates and the dolomites, but especially cavern-forming limestones; second, thin-bedded strata of chert or highly siliceous shales; third, pervious beds of clay-shale or calcareous shale. Sandstones and massive or impermeable strata are commonly barren. The presence of organic matter in the rock appears to have exerted a favorable influence on the deposition of the ore. That the ore has been deposited in these horizons and not in the intervening beds appears to be due to the structure and chemical composition of the productive stratum and to physical conditions that have supervened,—causes that are discussed in detail in the chapters on the occurrence of the ores in the several geological formations.

*Occurrence of the Ore-Deposits.*—All the deposits of lead- and zinc-ores in the Ozark uplift belong to the great class of fissure-fed impregnations, and may be designated as "runs," a term by which this form of deposits is known to the miners. A run may be described as an irregular ore-body, formed at the intersection of an ore-horizon with a vertical fissure. The roof and floor of the ore-deposit are formed by the massive, unmineralized beds which bound the favorable stratum above and below. Laterally the ore-body extends on either side of the plane of the fissure for an irregular distance, which depends upon the extent to which the rock was brecciated and fractured, allowing the mineral-depositing solutions to penetrate its mass. Longitudinally the ore-deposit or run stretches the length of the section of the fissure which remained open during the formation of the ore. Thus, in its simplest form, a run is limited vertically and laterally, but longitudinally it usually has a considerable extension. It is an ore-body which extends beyond the walls of the fissure through which the mineral-depositing solutions were introduced. Where a system of closely adjacent parallel fissures intersects an ore-horizon, the resulting runs are often connected laterally by ore, so as to form an irregular compound run. Such compound runs most frequently occur where the ore-horizon has been intersected by different systems of fissures and cross-fissures, resulting in a more complete and extensive brecciation of the rocks, and thereby allowing the ore-depositing solutions that are introduced through different fissures to

intermingle. The extensive mines of Joplin and Webb City, Missouri, and Galena, Kansas, belong to this class of compound runs.

The dimensions of simple runs vary greatly, but they are commonly 10 to 50 feet wide, 5 to 30 feet high, and from 100 to 300 feet long, these dimensions being exceeded only in exceptional cases. At Webb City there are compound runs which extend with an irregular course 300 to 600 feet longitudinally, the width varying from 75 to 150 feet, and the height of the ore-body from 40 to 60 feet.

In many mining-districts of the Ozark area, runs of ore occur in the stratified formations at different geological horizons, and the same fissure or system of fissures form runs, situated one above another at the several intersections with the different ore-horizons.

A run resembles a fissure-vein, in that the ore is deposited from solutions which ascend through a fissure from an unknown source in depth; but in fissure-veins of the simplest type the ore is included between the walls of the fissures, and has an extension in depth that is more or less continuous and unbroken, while in runs the ore is confined to the favorable strata and is deposited outside of the walls of the fissures; the fisures are usually barren, except where they traverse the ore-horizons. The occurrence of mineral deposits in the form of runs is not confined to the lead- and zinc-mines of the Mississippi valley; ore-deposits of this form exist in many localities in the mining regions of the Rocky Mountains, in situations where the sedimentary rocks are nearly horizontal in bedding and have been intersected by vertical fissures, introducing the ore-forming solutions.* The relation of runs to other forms of mineral occurrence is shown in the annexed general classification of ore-deposits, based upon the manner of formation and origin of the minerals. For convenience of study, the great class of deposits formed by ascension is further subdivided with respect to the character of the enclosing strata.

## Classification of Ore-Deposits.

### *Division with Respect to the Forces Giving Rise to the Deposits.*

I. Deposits formed by the action of mechanical forces. Examples: Placers and auriferous conglomerates.

II. Deposits formed by the action of chemical forces.

(This class is further subdivided as follows:)

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* This subject is more fully discussed in the chapter "The Lead and Zinc Mining Regions of the Mississippi Valley Compared."

*Division with Respect to the Origin of the Minerals, whether Derived from the Enclosing or Adjacent Strata or from an Exotic Source.*

II[1]. Irregular deposits formed by lateral secretion or segregation from the enclosing or adjacent strata. Examples: Deposits of manganese and bog iron-ores; certain carbonate ores of iron of the Coal-Measures, etc.

II[2]. Deposits in which the origin of the ores is in mineral-solutions ascending through fissures from some unknown source in depth.

(This class is further subdivided as follows:)

*Division with Respect to the Structure or Character of the Enclosing Strata.*

II[2].—*a.* Deposits confined to the walls of the fissures through which the mineral-forming solutions were introduced. Example: Fissure-veins.

II[2].—*b.* Irregular deposits extending beyond the walls of the fissures and impregnating the country-rock. Examples: Mineralized lodes or zones; impregnated beds or runs, and deposits filling pre existing caverns.

## Deposits of the Lead- and Zinc-Ores in the Cherokee Limestone of the Subcarboniferous.

*Stratigraphical Geology.*—The Cherokee limestone covers an area of more than 4000 square miles in the southwest part of the Ozark uplift, extending from the vicinity of Springfield, in Greene county, Missouri, to Grand river, in the northwest portion of Indian Territory. In Missouri this limestone is the prevailing surface-formation in the counties of Greene, Lawrence, Jasper, and Newton; it covers the southeast part of Cherokee county, Kansas, the northeast portion of Indian Territory, and a limited area of northwestern Arkansas.

When not denuded, this formation has a thickness of 185 to 220 feet. In the area covered by the Cherokee limestone the strata are nearly horizontal; gentle synclinal and anticlinal folds give a slight undulation to the surface. Along the course of the streams the region is cut by shallow ravines, while the divides are broad, high prairies. Fossils are abundant in this formation, which is probably the representative of the Warsaw or St. Louis epoch of the Subcarboniferous. The Cherokee formation is made up of beds of limestone irregularly interstratified with layers of chert. A marked variation is noticed in the relative proportion of the chert and limestone; in localities frequently but a short distance apart, the Cherokee is seen to change from a massive limestone with only occasional nodules or included layers of chert, to a stratum made up of alternate thin beds of chert and limestone, in which the chert exists in larger proportion.

Analyses of the Cherokee limestone show that it is uniformly a remarkably pure carbonate of lime, averaging from 98 to 99 per cent. of carbonate of lime with traces of magnesia, alumina, oxide of iron, and insoluble matter. Organic matter and bitumen are present in appreciable quantities, and from the solution of the rock by the chemical action of surface-waters the bitumen is liberated and collects as a thick pitch in the cavities. Owing to the purity of this limestone and its coarsely-crystalline character, it is readily attacked by surface-waters, subterranean erosion forming numerous caves and sink-holes where this limestone outcrops near the surface. The chert of the Cherokee formation is white, bluish-white, or buff in color, breaking with a smooth, conchoidal fracture. By analysis it contains 98 to 99 per cent. of silica, with traces of alumina and oxide of iron. About 3 or 4 per cent. of the silica exists in the hydrous condition, and is soluble in a solution of potassium hydrate. The chert of the Cherokee is cleanly separated from the interstratified limestone; though so intimately interbedded with the latter, the siliceous nodules and layers occur pure and distinct in the mass of the calcareous rock.

*Areal Location of the Ore-Deposit.*—The Cherokee limestone is not everywhere ore-bearing, but, following the general law of mineral occurrence, the ore-deposits have been formed only in local areas of disturbance. Between and surrounding such areas of mineralization extend broad barren tracts of undisturbed strata. The larger number of the productive mining-districts are grouped near the marginal belt of the Ozark uplift, in such a situation that the movements of elevation that have taken place and the consequent disturbance of the strata have been more profound and extensive than in the central plateau. Exceptions may be noted of mineral districts situated in the central area, where the rocks are horizontal, although much disturbed and cross-fissured. A marked instance of such occurrence is in the mining-camp of Aurora, in Lawrence county, Missouri, and the belt of deposits traceable from this district east to the vicinity of the city of Springfield.

It is probably futile to attempt to reduce to a general law, or to define in belts, the location of the ore-districts in this region. From the complex nature of the movements of disturbance that must have taken place, which alone appear to have influenced the special mineralization of certain areas, such attempts at broad generalization must be imperfect and liable to error.

*Occurrence of the Ore.*—Broadly considered, the ore-deposits are

mineralized zones of brecciated chert, more or less intermingled with limestone and the products of its alteration and decomposition. These mineralized zones or compound runs show, in many districts in the southwest, a marked tendency to form in the areas of intersection of different fissure and cross-fissure systems, and to be favorably influenced by the local occurrence in the Cherokee formation of thick strata made up of thin layers of inter-stratified chert and limestone.

As the natural result of the manner in which the ore-bodies in the Cherokee have been formed, and of the peculiar character of the enclosing rocks, they are very irregular in shape. The ore-deposits are limited only by the boundaries of the brecciated zone, the extent of the mineralization in the pervious and shattered beds, and the thickness of the favorable stratum or geological horizon. Many of the compound runs are of remarkable size, especially in the vicinity of Webb City and Joplin, Missouri, and Galena, Kansas, where stopes occur 75 to 150 feet wide, 40 to 80 feet high, and 200 to 400 feet long, from which all the extracted material has been milled. The smaller runs are 15 to 50 feet in width, 5 to 30 feet in height, and continuous in ore for a longitudinal distance of 100 to 500 feet. In one instance, near Joplin, Missouri, a run of ore was traced by connected workings for a length of nearly 1000 feet on the course of the fissure.

The fissures that traverse the ore-bodies and form the channels through which the mineralizing solutions have entered show, in some deposits, particularly in the vicinity of Galena, Kansas, strongly marked polished and striated wall-faces; but commonly the course of the fissures is indicated by the greater disturbance of the adjacent strata, the tabular-sheeted structure of the breccia forming the cheeks of the faulting-planes, and the presence of vugs and open channels in the ore-bodies.

The ore-deposits of the southwest do not invariably occur in the form of runs. In a few mines in Jasper and Newton counties, Missouri, nearly vertical fissures traverse the Cherokee limestone without disturbing the stratification or producing any brecciation except that of the rock included between the cheeks of the fissure, so that in the deposition of the ore the solutions could not escape from the fissures and penetrate the wall-rocks, but deposited the ore in the breccia included between the walls, forming ore-bodies which are vertical tabular sheets, simulating in structure and occurrence the ore-shoots of fissure-veins. A fissure of this character near Joplin, Missouri,

has a dip of 45° to 55°, and carries an ore-body stoped to a depth of 60 feet. The floor of the stope, for a length of 200 feet, is continuously in ore with a width between the walls of 4 to 12 feet. The ore does not penetrate the horizontal beds of limestone, chert, and shale, but is confined to the fissure, the walls of which are rough and irregularly eaten out by the ore-depositing solutions. Future exploration alone will show how such ore-bodies, resembling the shoots of ore in fissure-veins, will behave in depth when followed into the underlying formations.

*The Gangue.*—The gangue of the lead- and zinc-ores is made up of the rocks of the Cherokee formation and the products of their alteration, chert usually predominating. It occurs either as shattered beds, the strata retaining the original horizontal position and bedding; or, if the movements of disturbance and settling have been great, the rock is converted into a breccia of angular fragments mingled in the most confused manner, in which all stratification is destroyed. In many districts masses of drab-colored, coarsely crystalline dolomite surround the ore-bodies or occur in them, in which case they are more or less mineralized. Occasionally crystalline pink or white dolomite forms the cement of the breccia; more commonly a peculiar dark-colored silicified rock, resembling in appearance a fine-grained quartzite, fills the interspaces in the brecciated zones, and is frequently impregnated with ores. This gangue-rock, named by the writer cherokite, occurs only in connection with the ore-deposits in the Cherokee limestone in the southwest. It is the prevailing gangue of the zinc-mines at Galena, Kansas, and is associated with the ores of lead and zinc in the Joplin, Granby, and Webb City districts in Missouri.

Unaltered limestone forms the gangue of the ore in a few mines. Clay-shales and calcareous shales are the gangue of some mines in the upper beds of the Cherokee. Tallow-clay is abundant in the chert-breccia near the surface at Granby and Aurora, Missouri.

Dolomite results from alteration of the Cherokee limestone, and is connected directly with the formation of the ore-deposits. Broad tracts covered by the Cherokee formation stretch for miles in the barren intervals between the mining-districts in the southwest, the calcareous beds showing no evidence of alteration until an area of disturbance and faulting is reached, where the limestone is often converted into dolomite in the belts along the sides of the fissures. The effect of this dolomitization is to change the fine-grained structure of the limestone to that of coarsely crystalline dolomite, and to

obliterate all fossils and evidences of organic origin; and were it not for the horizontal bands of chert in the mass of the dolomite and the occasional preservation of bedding-planes, there would be nothing to indicate that the rock had once been stratified. The area adjacent to the fissures over which the limestone is altered to dolomite is often of much greater extent than that of the ore-deposits, and large masses of dolomite surround and separate the ore-bodies from the unaltered limestone-strata.

This alteration of limestone to dolomite has not taken place to the same extent in all the mining-camps of the region. In some localities all forms of dolomite are absent, either owing to the more or less complete removal of the limestone by the action of surface-waters prior to the dolomitization, thus leaving little material for the solutions that deposited magnesia to act upon, or by reason of the absence of magnesia in the solutions which formed the ore. The dolomite is a soft to medium hard, dark gray rock, with a coarsely crystalline structure, made up of white crystals of dolomite, one to three sixteenths of an inch long, embedded in dark drab-colored cement. The following analyses made by Mr. L. G. Eakins, U. S. Geol. Survey, from samples taken near Joplin, Missouri, show a difference in composition, in great part due to the variable amount of the insoluble residue which formed the cement of the crystalline mass.

*Analyses of Dolomite.*

| | No. 1. | No. 2. |
|---|---|---|
| Lime, | 21.46 | 28 72 |
| Magnesia, | 14.79 | 17.36 |
| Alumina and sesquioxide of iron, | 1.32 | 1.03 |
| Insoluble residue, | 29.77 | 11.66 |
| Carbonic acid by calculation, | 33.13 | 41.55 |
| | 100.47 | 100.32 |

Cherokite forms the cement of the chert-breccia in the ore-bodies. It commonly occurs as a brown or drab-colored rock, hard, dense and tough, breaking with difficulty under the blow of a hammer with a coarse, rough fracture. Analyses and microscopic examinations of samples of cherokite show that this rock has been formed by the silicification of the residual sandy mud resulting from the dissolution of the Cherokee limestone by waters charged with carbonic acid. The formation of the cherokite seems to have closed the ore-depositing period, this silicification of the gangue having taken place subsequent to the formation of the ore. Of the follow-

ing analyses of cherokite, Nos. 1 and 2 were made by L. G. Eakins, U. S. Geol. Survey, and No. 3 by the St. Louis Sampling and Testing Works. Sample No. 1 came from Joplin, Missouri, and Nos. 2 and 3 from Galena, Kansas.

*Analyses of Cherokite.*

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| Silica, . . . . . . . | 95.77 | 97.33 | 94.72 |
| Alumina and oxide of iron, . . | 1.84 | 1.89 | 4.00 |
| Lime, . . . . . . . | 0.54 | 0.11 | 1.18 |
| Magnesia, . . . . . . | 0.24 | 0.09 | trace. |
| Water, . . . . . . . | 1.17 | 0.77 | |
| | 99.56 | 100.19 | 99.90 |

Under the microscope, thin sections of cherokite show a highly crystalline structure, with imperfect interlocking crystals of quartz as the predominant mineral, and spots of dark bitumen, or carbon, and scattered oölitic grains, probably derived from the limestone. Cherokite is frequently impregnated with blende and galena; intermixed with brecciated chert it forms the prevailing ore in many mines in Jasper county, Missouri, and Cherokee county, Kansas. On account of its extreme hardness and specific gravity it cannot, without difficulty, be cleanly separated from the blende.

Occasionally masses of the soft residual mud, resulting from the subterranean erosion of the limestone, that from some cause have escaped silicification, are found in the ore deposits, and not uncommonly carry very perfect disseminated crystals of blende and galena. By the oxidation and removal in solution of the minerals included in the mass of the cherokite, the rock is converted into a skeleton. Where the rock was originally densely mineralized, the resulting skeleton is light and cellular, and the cavities show the imprints of the faces of the crystals which once filled them. So perfect are some of these moulds in the rock that casts can be taken in wax reproducing the form of the crystals. The minerals thus decomposed and removed were in all cases minerals of primary origin, blende and galena, and rarely pyrite; calcite, barite and other minerals of recent deposition have not been observed included in cherokite.

*Disposition of the Ore.*—The original form in which the ores of lead and zinc were deposited in the Cherokee formation was that of the sulphides, galena and zinc-blende. These ores appear to have been deposited in two ways, by replacement and by crystallization. By replacement, a chemical interchange takes place; a particle of

rock is dissolved and removed by the ore-depositing solutions, while at the same time a particle of ore is formed in its place. By crystallization, the galena and blende fill the interstices in the breccia and line cavities in the mass of the ore. The chert-fragments of the ore-bodies are very rarely penetrated by blende and galena, owing to the impervious and insoluble character of that rock. By this metasomatic replacement, ore has been deposited in the mass of the limestone-fragments in the breccia and in all the calcareous material, whether limestone or dolomite, throughout the ore-body. The small size and crowded growth of the crystals of blende which make up the great mass of the ore-bodies in certain mines, is evidence of a crystallization from concentrated solutions; as the solutions became weaker, the blende and galena of later deposition formed large crystals.

*The Ores.*—Only in exceptional cases are the ores of the Southwest sufficiently free from gangue to allow them to be shipped without dressing. In most mines all the ore that is extracted requires to be crushed and concentrated by washing to clean the mineral from the gangue and to separate the galena from the blende. The ores when thus concentrated are remarkably pure and command a high price. This is due in part to the general absence of iron pyrites in the ores of the region, and in part to the ease with which the ore is cleanly separated from the gangue.

The yield of the ore varies: two to five tons of the richest ore produce one ton of concentrates; while in the case of the poorer ores, 10 to 20 tons are required to yield one ton of concentrates.

*Vertical Distribution of the Ores in the Deposits.*—Where blende and galena occur in the same ore-body, the blende usually predominates in depth, often to the total exclusion of the lead-ore in the lower portions of the deposits, while galena is commonly found in formations near the surface. There is no sharp line of demarkation between the blende and galena in the deposits, and in the zone of transition the two minerals are intermingled. The blende in the lower and outer parts of the ore-body is usually free from galena and in the central and upper portions gradually gives place to the lead-ore.

In certain localities in the Southwest, the ore-deposits are not confined to a single geological formation, but, following the fissures, channels and openings in the strata, extend vertically from one horizon to another. Deposits of this character occur near Webb City, Missouri, where the Cherokee limestone is overlain locally by shales

of the Coal-Measures, and show a more strongly defined separation of the ores of the two metals; the Cherokee carrying deposits of blende with scarcely a trace of galena, while the galena is concentrated in the superficial formation. This peculiar vertical distribution of the lead and zinc has been noted not only in the deposits of the Southwest, but also in the mines of the Upper Mississippi region and of certain mining districts of Europe.*

The production of galena in the mines is not as great as formerly, owing to the fact that the deposits near the surface are mostly worked out, and as the explorations are pushed in depth the relative output of blende constantly increases. At present date the production of zinc-ores is from 5 to 20 times that of galena in the different districts, averaging for the entire Southwest about 10 tons of zinc-blende to one ton of galena.

*Alteration of the Ores.*—In most of the mines in the Southwest very little alteration of the ores has taken place since their deposition. At the mining-camps of Granby and Aurora in southwest Missouri, however, an extensive alteration of the ores has occurred; the blende is converted into calamine or rarely into smithsonite, and the galena into cerussite. But the production of these oxidized ores is rapidly decreasing; the great proportion of the output of the mines of the Southwest is now galena and blende.

*The Minerals Constituting the Ore-Bodies.*

The minerals in the ore-bodies of the Cherokee limestone have been mostly formed by primary deposition; where the conditions were locally favorable, a secondary deposition has taken place from oxidation and the action of the surface-waters on the primary deposits.

The minerals of primary deposition in the Cherokee limestone are:

*Sulphides.*—Blende and galena, constituting the principal ores. Cadmiferous blende, locally abundant in some districts. Existing as subordinate minerals and probably resulting chiefly from secondary deposition: pyrite and marcasite, chalcopyrite (rare).

*Sulphates.*—Barite locally occurs in a few mines in the Southwest, but is usually of secondary formation.

*Carbonates.*—Dolomite, formed by the alteration of the Cherokee limestone.

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* "Mineral Wealth of the U. S. Lead-Mines of the Upper Miss.," by J. D. Whitney, *Geol. Sur. of Wis.*, vol. iv., T. C. Chamberlin.

*Silicates.*—Cherokite, resulting from the silicification of the residual sediment formed by the decomposition of the Cherokee limestone. Quartz occurs rarely in the deposits of the Cherokee.

The minerals of secondary deposition are:

*Sulphides.*—Pyrite and marcasite, formed from the iron derived from the wall-rocks. Blende, galena, chalcopyrite and greenockite, produced by alteration from the primary ores in the zone of oxidation in the upper portions of the ore-bodies, and re-formed as sulphides by the reducing action of organic matter in the deeper levels.

*Sulphates.*—Anglesite, from alteration of galena. Barite, occurring locally, and probably derived from the gangue of the ore. Gypsum, a rare mineral in the Southwest, though sulphate of lime is present in all the mine-waters. Soluble in water and derived from the oxidation of the ores: sulphate of zinc and several different sulphates of iron, occurring as efflorescences in the old workings of the mines. Sulphate of cadmium is present in the waters of many mines. Sulphates of magnesia, lime and the alkalies are also present in mine-waters, and result from the action of metallic sulphates upon the gangue and country-rock.

*Carbonates.*—Resulting from the oxidation of blende and galena: smithsonite, hydrozincite, aurichalcite (rare), cerussite and cadmiferous smithsonite (rare). Derived from the gangue or from the wall-rock: dolomite and calcite.

*Silicates.*—From the alteration of blende: calamine and zinciferous tallow-clay. From decomposition of chert and limestone by surface-waters: tallow-clay.

*Phosphates and Chlorides.*—Pyromorphite (rare), a product of the alteration of galena.

*Organic.*—Bitumen set free in the decomposition of the rocks by surface-waters.

### *The Order of Deposition of the Minerals.*

The minerals forming the ore-bodies in the Southwest appear to have been deposited in a uniform order, which seems to be constant in all the mines examined where the facilities for observation were such that the paragenesis of the different minerals could be determined. This order of formation is:

*Minerals of Primary Deposition.*—1. Crystalline dolomite, frequently forming the wall-rock of the deposits.

2. Crystalline blende, becoming more perfectly crystallized as the

deposition proceeded, and often intermixed with galena in the ores of later deposition.

3. Crystalline and crystallized galena.

4. Pyrite, occurring in relatively small proportion to the other minerals.

5. Cherokite and crystallized quartz (rare).

*Minerals of Secondary Deposition.*—From the nature of their deposition, the paragenesis of the minerals of secondary formation is greatly varied, and the same mineral may occur more than once in the series. While thus conforming to no absolute order, the secondary minerals may be arranged in groups according to the more commonly prevailing sequence of deposition, the series being thus continued:

6. Crystallized white and rose-colored dolomite, lining cavities in the ore-body and filling the interstices in the breccia.

7. Crystallized blende, usually of garnet or ruby-red color, often in small brilliant, translucent crystals. Crystallized galena, the commonest forms being the cube and cube-octohedron; the plain octohedron is of rarer occurrence.

8. Crystallized pyrite, marcasite, chalcopyrite, calcite and barite. Amorphous tallow-clay.

9. Anglesite, cerussite, calamine, smithsonite and greenockite, resulting from the alteration of the ores.

It may be noted that the primarily deposited ores are almost wholly composed of the simple sulphides of zinc and lead and of the gangue-minerals dolomite and cherokite. Calcite appears to be in all instances of secondary and late formation. Pyrite, marcasite and barite are probably of both primary and secondary deposition, but seldom occur other than in relatively subordinate importance.

### *The Cause of the Concentration and Deposition of the Ores in the Cherokee Limestone.*

For purposes of discussion the causes that have induced the ore-formation may be divided into three classes:

*Structural.*—In the Cherokee formation thin-bedded strata, especially where the limestone is interstratified with chert, are observed to be peculiarly favorable to ore-occurrence. Such thin and brittle strata of alternating limestone and chert, included between more massive and unyielding beds, were shattered by the slightest movement of disturbance or faulting, and subsequently, in the deposition of the ore, these fractured and brecciated strata afforded free

circulation to the mineralizing solutions, the effects being augmented by the greater number of bedding-planes. The coarsely crystalline structure of the limestone and its porosity and permeability also increased the action of carbonated waters and further aided in opening channels for subterranean circulation. The position of this geological formation, occurring near the surface over a great area, has likewise been an important factor, from the action of sub-aërial waters and from the increased extent of the brecciation due to fissuring and movements of disturbance; it being a well-recognized law that the fracturing and crushing of a stratum of rock by dynamic movements takes place the more readily and to a greater extent the less it is weighted by superincumbent strata.

*Chemical.*—The extreme purity of the limestone of the Cherokee renders it readily soluble in waters containing carbonic acid. Not only are the limestone strata thus dissolved and removed by the action of sub-äerial waters, but in the subsequent deposition of the ores, the limestone fragments that remain in these brecciated beds are metasomatically replaced by the ores. The limestone itself acts as a chemical precipitant and neutralizes any free acid or acid salts present in the ore-forming solutions, and the organic matter and bitumen originally contained in the calcareous rocks, but set free by their dissolution, constitute powerful reducing agents in the ore-deposition.

*Physical.*—Physical conditions antecedent to the formation of the ore, have influenced the localization of the deposits and greatly increased the extent of the brecciated zones. Prior to the formation of the mineral deposits, the Cherokee limestone, where it occurs near the surface, was subjected to the prolonged action of surface-waters; in the districts where the beds were faulted and disturbed, an extensive subterranean erosion of the calcareous strata has taken place. This removal of the limestone interbedded with the chert in the shattered and fissured belts caused a settling of the formation and of the superincumbent rocks, resulting in the more complete brecciation of the chert and in the formation, ultimately, of broad zones, consisting almost entirely of angular fragments of chert intermixed in the most confused manner, and mingled with residual clay of the eroded limestone.

The action of these combined physical and chemical forces began with the elevation of the Ozark uplift above the ocean at the close of the Subcarboniferous period, and continued with attendant faulting and disturbance of the strata for a vast period of time, during

which the Ozark area remained dry land—an interval when the climatic and atmospheric conditions are believed to have been, at least during the Coal-period, singularly favorable for the production of surface-waters charged with carbonic acid and the organic acids resulting from the decay of vegetation. At a much later age, when other dynamic disturbances produced a more profound and widely extended fissuring of the formations and inaugurated the period of ore-deposition, these zones of brecciated rock directly connected with the fissures and containing the chemical elements requisite to effect the reduction and precipitation of the metals, afforded free escape and circulation for the ore-depositing solutions and formed a matrix admirably fitted to receive the minerals.

## Ore-Deposits in the Magnesian Limestones of the Lower Silurian.

*Stratigraphical Geology.*—The rocks of the magnesian limestone series cover nearly four-fifths of the area of the Ozark uplift, reaching from the Missouri river south to the valley of the Arkansas, and from the Mississippi west to the headwaters of White river. This formation aggregates 1205 to 2000 feet in thickness and is made up of three or four distinct limestones, separated by strata of soft sandstone. The position of the beds is nearly horizontal, except where they are locally disturbed by dynamic movement. The limestones are composed of beds of very variable composition, shaly layers frequently alternating with thick strata of compact limestone. By reason of the irregular hardness of the different beds and the greater elevation of the area covered by the magnesian limestones, an extensive erosion has taken place. The topography is marked by long narrow divides, with steep and rocky slopes and high cliffs along the streams, constituting altogether the roughest and most mountainous region of the Ozark upheaval. Numerous caverns, some of great extent, exist in this section.

*Occurrence of the Ores.*—Lead- and zinc-ores are found at widely separated localities in the area covered by the magnesian limestone series in central, southern and southeastern Missouri and in the continuation of this formation into northern Arkansas. In general the ore-deposits are small, though in the early settlement of the country, large and very productive bodies of lead-ore were found in these limestones in southeastern Missouri and were worked for many years—but now most of them are exhausted.

The ore-deposits are found at certain favorable horizons in the

limestones of this series, in runs formed at the intersections of the horizons by faulting fissures. The intervening strata are barren. The ore-horizons are commonly shaly or thin-bedded strata; where the limestones occur in thick beds they are less frequently ore-bearing, and the sandstones of the series are everywhere barren. In northern Arkansas it is noticeable that thin-bedded, highly siliceous strata form the horizons, probably from the facility with which such brittle beds, inclosed between rigid strata, are shattered by the faulting movement and form a permeable matrix for the ores. Generally it is observed that in the limestones of this formation the previous character of the bed, rather than the chemical composition of the rock, has influenced the deposition of the ore. The solubility of dolomite in surface-waters has to some extent influenced the deposition, through the enlargement, by this agency, of the crevices and openings in the limestone.

In the deposits in the magnesian limestones, the small extent of the brecciation which has accompanied the faulting has induced a concentration of the ore-deposition within narrow limits, with the result that the ores of this formation are usually rich and free from gangue. The ores are in most part pure and capable of being hand-sorted for shipment; only the poorer ores are crushed and concentrated.

The more notable mineral occurrences in this formation are the prevalence of smithsonite in place of calamine, as the mineral resulting from the alteration of blende, and the deposition of crystallized barite and quartz in the gangue of the mines in certain localities. In southeastern Missouri barite frequently occurs as the gangue of galena, and the outcrop of the ore-bearing formation is characterized by a peculiar chert filled with nests of crystallized quartz, known by the miners as "mineral blossom." Crystallized pink dolomite, resembling that of the Cherokee limestone and possibly of similar origin, is occasionally found in the ore-deposits and fissures in the magnesian limestones of northern Arkansas.

### Deposits of Lead Ore in the Cambrian Limestones.

*Stratigraphical Geology.*—In southeast Missouri, in the lead-mining region of Bonne Terre, Doe Run and Mine la Motte, a dark brownish-black magnesian limestone forms the ore-horizon. The age of the formation may be Upper Cambrian (Potsdam). This limestone rests uncomformably on the higher points of the Archæan bed-rock at Mine la Motte and at Doe Run. In the deeper chan-

nels between the ridges of granite and porphyry the lead-bearing limestone overlies a soft sandstone. The thickness of the lead-bearing formation is 220 feet at Bonne Terre; at Mine la Motte it is locally much reduced by denudation, attaining 150 feet as a maximum.

The strata of the Cambrian are horizontal, or dip locally at gentle angles from some axis of disturbance. In the mineralized areas the beds have been subjected to extensive faulting. This dynamic action, measured solely by the vertical displacement of the strata, is most intense at Mine la Motte at the extreme southern end of the district, and decreases to the northwest, being smaller at the Doe Run Mine and smallest at Bonne Terre. At Mine la Motte a large faulting-fi sure bounds the workings of the mine on the west, and is connected with the master-system of fissures traversing the ore-body. The strata at this mine have been faulted by these fissures prior to the deposition of the ore; the vertical displacement of the beds is from 5 to 10 feet in the stopes, and the aggregate throw by this main faulting-fissure and its branches exceeds 100 feet. At Bonne Terre no considerable displacement of the strata has occurred; the workings of the mine are traversed by belts of parallel fissures with walls striated horizontally, showing that a lateral movement has taken place.

*Occurrence of the Ore.*—The galena occurs disseminated through the beds of limestone in crystalline grains from $\frac{1}{16}$- to $\frac{1}{2}$-inch in diameter, and also deposited in flat irregular thin sheets in the shaly partings between the layers of the rock. The position of the ore in the limestone is determined by the intersection of a system of nearly parallel vertical master-fissures, traversing the strata in a narrow belt, by one or more belts of vertical cross-fissures. The masses of galena occur around such places of multiple and complex intersection, where different systems of faulting-planes, intersecting on diverse courses, and crossed by smaller diagonal fractures, have brecciated *in situ* a large section of ground.

In the subsequent mineralization of the beds, the ore-depositing solutions, rising from below through the system of master-fissures, followed paths of easiest flow where the intersection of the cross-fissures aided in keeping the channel open, and on reaching the horizon of the black limestone, penetrated the fractured beds. The form and extent of the ore-body has been determined by the distance to which the solutions penetrated the fissured limestone from the channels by which they were introduced. The richest ore is usually

found about the intersection of the fissures, and as the ore-body is followed laterally it becomes poor as soon as the outer boundaries of the area of disturbance and fissuring are reached. The mineral-forming solutions deposited only galena and small quantities of iron pyrites carrying nickel and cobalt. Not a trace of zinc-blende occurs in these deposits in the Cambrian, though in the Magnesian limestones blende is found in considerable quantity in many mines of southeast Missouri. The ore-deposits may be described as thick beds of limestone irregularly impregnated with galena ; but on examination they are seen to be compound runs of unusual size, formed much in the same manner as the mines of the Southwest. The ore-deposits are of great size. At Bonne Terre a stope in the mine follows a belt of fissures for nearly 3000 feet; the width of the workings is 100 to 200 feet, and the height 25 to 60 feet. At this mine all of the extracted ore goes to the mill and is crushed and concentrated; the average yield as it is taken from the ground is about 8 per cent. of galena, equivalent to 6 per cent. of lead.

*Cause of the Accumulation of the Deposits of Galena in the Cambrian Limestone.*—At Bonne Terre the mineralized beds occur at a depth of 50 to 225 feet; at Mine la Motte they outcrop at the present surface of denudation. No subterranean erosion of the limestone has taken place; even the more prominent fissures have been but little enlarged by the circulation of surface-waters. The ore-bearing strata at Bonne Terre are overlain by beds of magnesian limestone of close texture, containing but little organic matter. These upper beds, though traversed by the faulting-fissures are but little fractured and are unmineralized. The underlying soft sandstones are also barren.

The causes of the deposition are, apparently : the presence of organic matter in relatively large proportion in the ore-bearing beds; the existence of numerous shaly partings between the layers of limestone; the pervious structure of the rock, which favors the penetration of the mineralizing solutions and the deposition of the ore by replacement; and the extensive fracturing of the strata by faulting movements, due to the brittle character of the formation, in which hard layers alternate with thin, soft, shaly partings.

*Production.*—From Mine la Motte, Doe Run and Bonne Terre the aggregate production for the calendar year 1888 was 20,750 tons of pig-lead. In 1889, the production was increased to 21,320 tons, forming nearly 60 per cent. of the total production of non-argentiferous lead in the United States for that year, or 11 per cent. of the yield of lead in the United States from all sources.

## Deposits of Argentiferous Lead- and Zinc-Ores in the Ouachita Uplift.

*Stratigraphical Geology.*—The ore-bearing rocks of southwestern Arkansas are metamorphic clay-shales and quartzites, probably of Calciferous or Trenton age, extending through the central ridges of the Ouachita uplift from Little Rock, Arkansas, into Indian Territory. Prior to the deposition of the ores, these rocks were strongly folded, metamorphosed and subjected to heavy denudation. In many localities in the area of the upheaval, dikes of igneous rocks are intruded into the older formations, and in the eastern section, in the vicinity of Little Rock and Hot Springs, Arkansas, extensive extravasations of elæolite-syenite occur.

*Dynamic Disturbances.*—The Ouachita uplift, like the Ozark area, was elevated above the ocean at the end of the Subcarboniferous period. The last great upheaval took place at the close of the Carboniferous; strata of the Coal-Measures being folded by the movement. The intrusion of the igneous rocks in the Ouachita area has been determined by Dr. J. C. Branner to have taken place in post-Cretaceous time.*

It is probable that the formation of the veins of quartz carrying silver, lead and antimony was due to these igneous disturbances; but the evidence so far obtained respecting the age of the deposition of the ores is of a negative character.

*Occurrence of the Ores.*—Deposits of silver-bearing lead- and zinc-ores are found at intervals scattered irregularly throughout the extent of the Ouachita uplift. The more prominent mining districts are the Kellogg mines near Little Rock, Silver City in Montgomery county, and Antimony City and Silver Hill, in Sevier county, Arkansas.

The ores occur in fissure-veins which have general northeast and southwest varying to east and west courses, parallel to the axis of the uplift. The fissure-character of these deposits is strongly marked; the veins dip at steep angles, from 40 to 90 degrees, and traverse the country in straight courses, in some instances indicated on the surface by outcrops of quartz. The fissures cut the bedding of the inclosing rocks on both strike and dip; the walls are slickensided and striated by the faulting-movement, and the crevices are more or less filled with material ground from the walls. Frequently the vein-material exhibits a tabular, sheeted structure, par-

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* *Reports Arkansas Geological Survey.*

allel to the cheeks of the fissure. The majority of the veins are narrow, usually averaging one or two feet in width, and seldom exceeding four or five feet. The ore-deposits form shoots confined to the fissures, and do not penetrate or impregnate the wall-rocks.

The prevailing ores are crystalline zinc-blende, carrying from a trace to a few ounces of silver per ton; crystalline galena with from 4 to 60 ounces of silver per ton, and iron pyrites and chalcopyrite containing traces of silver. In several mines argentiferous tetrahedrite occurs associated with galena and blende, together with a mineral resembling polybasite. These silver-minerals are very rich, assaying from 100 to 1200 ounces of silver per ton.

In Sevier county the veins carry deposits of antimony-ore (stibnite); in the same district lead- and zinc-ores are closely associated with the lodes of antimony; and in one occurrence, a vein which has produced stibnite near the surface, has changed at the depth of 90 feet to zinc blende and galena low in silver, but with little antimony. These antimony-ores are usually poor in silver. The vein-rock is either opaque white crystalline quartz with a banded structure parallel to the walls, or a breccia of angular fragments of the wall-rock, cemented by quartz. The minerals are disseminated through the mass of the quartz; the fragments of wall-rock in the gangue are unmineralized. Crystalline calcite and chalybite occur as subordinate minerals in the gangue of certain mines. Mispickel is found in small quantity in the antimony-lodes in Sevier county. The paragenesis of the minerals is obscure; the deposition has probably occurred from hot, alkaline solutions carrying silica and the metals; the minerals appear to have been simultaneously formed by crystallization in a magma of soft, gelatinous silica, which subsequently was converted into the crystalline quartz of the gangue. Since the deposition, very little alteration of the ores has taken place, the zone of oxidation extending but a few feet below the surface.

In occurrence, these argentiferous zinc- and lead-veins closely resemble the silver-bearing veins of the Rocky Mountain region, to which they are probably allied in origin, and from which they cannot in any way be differentiated in classification.

The greater proportion of the ores require mechanical concentration, though in certain mines the ores are sufficiently rich and free from gangue to be shipped after hand-sorting. Owing to various causes all of the mines of this region were closed at the time of my examination (March, 1891). In a number of localities the outlook

is such as to warrant further and more extended prospecting in depth.

## Deposits of Lead- and Zinc-Ores in the Wisconsin Uplift.

*Stratigraphical Geology.*—The formations of the Wisconsin-Iowa mining region lie almost horizontal, with a slight dip in a general southwest direction. In an ascending order occur the Potsdam sandstone, the Lower Magnesian limestone, the St. Peter's sandstone, the Trenton and Galena limestones, the Maquekota shale and the Niagara limestone. Over the greater portion of the mining-region the Galena limestone is exposed at the surface, the Niagara limestone and the Maquekota shale having been removed by denudation. Owing to this denudation and the prevailing southwest dip of the formations, the Trenton limestone occurs near the surface in the extreme eastern and northern sections of the mining-area, and the Galena limestone that remains uneroded increases in thickness to the south and west until near Dubuque, Iowa, the upper beds outcrop, thinly covered by the Maquekota shale, and finally disappear beneath the later formations.

*Dynamic Disturbances.*—The Wisconsin Island, together with all of the surrounding land, was elevated in the great continental upheaval at the close of the Subcarboniferous. The mining-region, like that of the Ozark uplift, has been continuously above water from the Carboniferous to the present time, nor was it covered in the Glacial period by the great ice-sheets or by the deposits of the Drift.

Two systems of fissures occur in the lead- and zinc-region; one with courses substantially north and south is characterized generally by small dimensions; the other, an east-and-west system, includes the great ore bearing crevices. These fissures are faulting-planes traversing all the different geological formations; as a rule they are nearly vertical, in a few instances dipping at angles of 35 to 45 degrees. They appear to have been formed at distinct periods; the north-and-south system is the older and has been faulted by the east-and-west master-fissures; the direction of the faulting movement was from west to east in a horizontal thrust, with very little vertical displacement of the strata. In a mine at Dubuque, Iowa, where the horizontal throw was determined by measuring the displacement of the north-and-south fissures by those of the east-and-west system, it was found to be 30 to 40 feet, while the vertical component of the movement was only 3 or 4 inches. The north-and-south fissures are usually less than a foot wide; the east-and-west crevices are much stronger, and the

evidences of the faulting movement produced by them are more pronounced. In the vicinity of Dubuque, Iowa, certain of the east-and-west fissures are from 5 to 20 feet wide between the walls, and have been traced by workings at intervals along their course for from 2000 to 6000 feet.

After the formation of the fissures a long period must have elapsed, during which the crevices and openings in the limestone strata were greatly enlarged by erosion, due to the circulation of sub-äerial waters, prior to the introduction of the ore.

*Occurrence of the Ores.*—The great ore-bearing rocks are the Trenton and Galena limestones, aggregating 300 feet in thickness. Ore has been found in small quantities in both the overlying and underlying geological formations; but the only horizon other than the Trenton that promises to carry workable deposits is the Lower Magnesian limestone.

Conforming to the general law of mineral occurrence, the ore-deposits are grouped in fissured and disturbed areas, constituting the mining districts; and where faulting fissures are absent, the ore-horizons, over broad tracts, are barren.

*Ore-Horizons.*—Certain horizons, locally called openings, in the Trenton and Galena limestones, are found to be ore-bearing to a much greater degree than the intervening beds. Such horizons are often persistent over considerable areas, and are, commonly, thin-bedded, shaly, and porous strata. Less frequently, layers of massive limestone form the ore-bearing beds, where the rock, from its physical structure or chemical composition, is readily attacked by carbonated waters. Nearly all the ores mined are extracted from the east and west crevices; the north-and-south fissures commonly carry thin sheets of ore, and are but little worked. Where the two systems of fissures cross in an ore-horizon, the ore-deposit in the east-and-west crevice is often enriched and of greater size near the intersection.

The form of the ore-deposits is that of runs, which occur where the favorable horizons are traversed by faulting fissures. The course of the runs conforms both to the strike of the fissures and to the nearly horizontal position of the strata. These runs, while subject to great variation, are of two general forms: First, where thin-bedded rocks constitute the ore-horizon, the ores are often deposited by replacement, impregnating the layers of the rock on one or both sides of the fissures, and for a considerable distance beyond the walls. Second, in horizons in the massive beds of the limestone, and in the less permeable shaly strata, the ores have been deposited by crys-

tallization, and form more or less regular sheets, included within the eroded walls of the crevices. When ore-bodies of this character are of considerable longitudinal extent, and are continuous for some vertical distance in the fissures, they resemble somewhat the ore-shoots of fissure-veins.

The gangue of the ore in the deposits within the crevices is commonly composed of fragments of the wall-rock, mingled with the clay resulting from their decomposition. In the impregnated beds, the gangue consists of the disturbed and slightly altered rock which forms the ore-horizon. The ores from the impregnated beds usually have to be crushed and concentrated, while most of the ores deposited in the open crevices require hand-sorting only to prepare them for sale.

In the vertical distribution of the ores in the deposits, galena is more abundant near the surface, while blende prevails almost exclusively in depth. In the northeast section of the mining region, blende occurs in large proportion in the Trenton and in the lower beds of the Galena limestone, even under conditions where these formations are exposed at the surface.

*Minerals Associated with the Ores.*—Iron pyrites and marcasite are very abundant, and appear to have been of primary deposition, thus indicating the presence of a large amount of iron in the ore-forming solutions—a view confirmed to some extent by the large percentage of iron contained in the blende. Chalcopyrite also is abundant in the northeast section of the mining region, and, in some localities, it is mined in limited quantities. Smithsonite usually results from the alteration of blende; calamine, from the absence of any form of soluble silica in the ore-deposits, is of rare occurrence. Although the wall-rocks are highly magnesian, dolomite rarely occurs in the gangue, though calcite is quite common. Barite is also comparatively rare, though more prevalent in the deposits in the Trenton limestone.

*Order of Deposition of Minerals.*—The minerals constituting the ore-bodies usually have been deposited in the following order:

1. Crystalline pyrite, forming a thin band separating the ore from the wall-rock.
2. Crystalline blende.
3. Crystalline and crystallized galena.
4. Crystalline and occasionally crystallized pyrite and marcasite.
5. Crystalline and crystallized calcite.
6. Crystalline barite.

*Cause of the Accumulation of Ores in the Trenton.*—The existence of the ore-deposits appears to be due :

1st. To the exposure of the Galena limestone for a great length of time, antecedent to the introduction of the ores, to atmospheric agencies, and to subterranean erosion. This action of the oxidizing surface-waters not only enlarged the then existing water-channels, openings, and crevices, but softened and decomposed the wall-rock and the permeable strata adjacent to the fissures, thus preparing a favorable gangue for the ores in the subsequent mineralization.

2d. To the great solubility of both the Trenton and Galena limestones in waters containing carbonic acid. The Galena limestone and certain layers of the Trenton are highly magnesian, approaching a pure dolomite in composition. From the greater solubility of magnesian than of lime carbonate in carbonated waters, these dolomites are less resistant to subterranean erosion than the limestones. Surface-waters also more rapidly erode the Galena limestone on account of its soft, coarsely crystalline structure and the irregular occurrence of hard and soft spots in the rocks.

3d. To the presence of interstratified soft and pervious shaly beds, affording free circulation for subterranean waters.

4th. To organic matter contained in the rock, and most abundantly in the shaly beds. This, by its oxidation, has, to some extent at least, furnished a source of carbonic acid to the circulating waters, and in the deposition of the ores has acted as a precipitant of the metals.

*The Occurrence of Lead-Ores in the Lower Magnesian Limestone.*—Small deposits of lead-ore were mined in early days from the Lower Magnesian limestones, and "patch-diggings," or deposits of float-ore resulting from the erosion of this formation, were found in a number of localities on the northern and western borders of the mining region. The only mine at present worked in the Lower Magnesian is situated about 5 miles northwest of Lansing, Iowa, in the extreme northwest border of the lead-region. At this locality a strong vertical faulting fissure, having a course nearly north and south, traverses the lower beds of this formation. The crevice averages from 5 to 10 feet in width, and is filled with tough red clay, which forms the gangue of the ore. The galena occurs in a vertical sheet, 3 to 4 inches thick, embedded in the clay. The ore is very pure, assaying over 70 per cent. of lead and 2.6 ounces of silver per ton. About 25 tons of clean ore have been shipped from this mine. This occurrence of lead in the Lower Magnesian limestone is of interest as showing

the great vertical range of the ores in the geological formation of this region.

## The Lead- and Zinc-Mining Regions of the Mississippi Valley Compared.

In this discussion it is necessary at the outset to separate the Ouachita uplift with its Appalachian structure, its highly disturbed and metamorphosed rocks, its igneous intrusions and silver-bearing fissure-veins, from the other areas of upheaval in the Mississippi valley, and to place it with the silver-mining regions of the Rocky Mountains, to which this elevated range in southwestern Arkansas has so many points of resemblance. The Ouachita uplift cannot be classed with the lead- and zinc-producing regions proper, as silver is the more valuable and important constituent of the ores.

*Unity of Plan in the Occurrence of the Ore-Deposits.*—The lead- and zinc-regions of the upper and lower Mississippi have the following points in common:

1. The mining regions are located in great insular areas, elevated above the general level surface of the Mississippi valley.

2. These uplifts have a nucleus of Archæan rocks, surrounded by encircling belts of the Palæozoic formations, and have been centers of recurring dynamic action from Archæan to Tertiary time.

3. The mineral regions have been continuously above the ocean since the opening of the Carboniferous period, and are non-glaciated and driftless.

4. The ore-deposits are confined to limited areas, distributed without apparent regularity over the uplifted regions, but showing some tendency to group near the marginal belts rather than in the central plateaus.

5. The mining districts are local areas of disturbance and faulting of the strata.

6. The deposits of lead- and zinc-ores are not confined to any special geological formation, but occur to a greater or less extent in all the limestones, shales and chert-beds from the Cambrian to the Coal-Measures. Neither is any specific horizon found to be ore-bearing in all sections, but each mining region has its own peculiar productive formation. The ore-bearing horizons are predetermined by the position and structure of the formations, the permeability of the beds, the solubility of the calcareous rocks in carbonated waters and the abundance of organic matter in the strata.

7. The absence of igneous rocks in the sedimentary formations

and of all evidence of igneous action in connection with the deposition of the ores, other than such as may have taken place deep in the earth's crust.

8. The ore-deposits occur in runs or impregnated beds and are invariably associated with faulting fissures. The location of the ore-bodies is in many instances determined by the *foci* formed by the intersection of a system of master-fissures by belts of cross-fissures and diagonal faulting-planes.

9. The minerals and ores have been deposited in a definite order of succession; and this paragenesis, at least for the minerals of primary deposition, appears to be uniform in each mining region, though somewhat varied, for the minerals constituting the series, in the different sections of the Ozark and Wisconsin uplifts.

10. Simple minerals, few in number, constitute the ores; the zinc and lead were originally deposited as blende and galena. Quartz is rarely present in the gangue; and all minerals of gold, silver, antimony and arsenic are absent from the ore-bodies. Galena commonly occurs near the surface, giving way in depth to blende; this vertical distribution is not invariable nor yet peculiar to these regions, for it is also reported of the deposits of these ores in the stratified rocks of Europe.

*Prominent Features of the Occurrence of the Argentiferous Lead- and Zinc-Ores in the Ouachita Uplift.*—These are:

1. The evidences of intense dynamic action, not only in the folding and metamorphism of the rocks, but in the later disturbances in post Carboniferous and post-Cretaceous times.

2. The occurrence of extensive igneous intrusions that were probably connected with the formation of the ore-deposits.

3. The ore-deposits occur in districts distributed irregularly through the central axial belt of the uplift.

4. The ores are deposited in fissure-veins and do not extend into the wall-rocks, but are included within the crevices. The form of the deposits is that of shoots, or sheets of ore bounded by the walls of the fissure and having an indefinite extension longitudinally and in depth.

5. The deposition of the ores does not seem to have been in any way influenced by the character or chemical composition of the wall-rocks.

6. The minerals constituting the ores and forming the gangue have probably been simultaneously deposited from heated alkaline solutions carrying silica and the sulphides of the metals.

7. The complex character of the minerals associated in the fissures, including argentiferous galena, blende, pyrite, chalcopyrite, stibnite, mispickel, argentiferous tetrahedrite, polybasite (?), chalybite, ankerite (?), calcite and quartz.

*Cause of the Peculiar Association of the Minerals in the Deposits.*—The lead- and zinc-ores of the Ozark and Wisconsin uplifts, when compared with those of the Ouachita uplift and of the Rocky mountains, differ radically from the complex minerals of the silver-bearing fissure-veins, in the more simple occurrence of the few minerals that form the ore and in the absence of all minerals of arsenic, antimony and silver as well as of crystalline quartz. It is probable that this peculiar occurrence of the minerals is due to the formation of the ore-deposits under special physical and chemical conditions; that the mines of the West and of the Ouachita uplift have resulted from a deposition from solutions of high temperature and pressure, arising from the proximity of intrusions of igneous rocks and of widespread igneous action, while in the Ozark and Wisconsin areas no igneous intrusions have occurred and the minerals have been deposited by solutions of relatively lower temperature.

The prevailing uniform order of superposition of the minerals in the deposits in the Cherokee limestones, dolomite coming first and being followed in order by blende, galena and cherokite, may be due to a deposition effected by successive upflows of solutions charged with magnesia, zinc, lead and silica—upflows that were regional in their extent and that resulted from conditions existing in the source of supply in the crystalline rocks. In the ore-bodies of the Cherokee the formation of dolomite and the deposition of the ores of lead and zinc graduate insensibly the one into the other in the order of time; no sharp line of demarkation is observed to separate these minerals in the deposits.

The dolomitization was most intense in the early stages of deposition; great masses of the Cherokee limestone were then altered to dolomite, the action continuing with diminishing energy through the ore-forming period. After the culmination of this dolomitization, blende appears to have been formed; the deposition of the blende gradually giving way to that of the galena, so that in the zone of transition the ores of the two metals occur intermingled in the ore-bodies.

The epoch of the silicification of the gangue closed the ore-forming period and seems to have taken place after the primary formation of the ores had entirely ceased.

The occurrence of lead near the surface and of zinc in depth, seems to be the result of causes which are to a great extent independent of the geological age or nature of the rocks in which the deposits occur, and is apparently influenced by the position of the formation with respect to the surface. It is possible that the deposition of the galena may be due to the cooling and diminished pressure of the mineral-solutions on reaching the surface, and to the mingling of the ore-forming solutions with surface-waters carrying organic matters, both in suspension and in solution, and also nitrogenous compounds, ammonia, carbonic acid, oxidized alkaline salts and free oxygen. The peculiar manner in which cinnabar is now forming at Sulphur Bank, California, by the action of ammonia in the ascending mineral solutions has been investigated by Becker.* The finding of weighable amounts of sulphate of ammonia in crystals of barite from the lead- and zinc-mines of central Missouri by Dr. Charles Luedeking of St. Louis, is an indication that salts of ammonia may have been present influencing the deposition of the minerals, under conditions not hitherto suspected.†

The tendency of galena to deposit in rocks containing bitumen and organic matter, has undoubtedly, to some extent, influenced this concentration of the galena in certain strata; but the constancy of the occurrence of lead-ores in formations near the surface, the world over, shows that the cause of this vertical distribution of the ores must be sought in other directions than in the chemical composition, or lithological peculiarities of the formations carrying the deposits.

*Origin of the Ores.*—The evidence obtained in this investigation indicates that the ores and the associated minerals have all been deposited from aqueous solutions, probably of moderate or normal temperature and pressure, and that the fissures connected with the ore-bodies have formed the channels through which the mineralizing waters were introduced. It is also evident that the lead and zinc were not derived from the geological formations in which the deposits occur, or from the overlying or underlying sedimentary strata, but that the source of the metals was exotic and was probably deep-seated in the primitive rocks.

*Form of Occurrence of the Ore-Deposits of the Upper and Lower Mississippi.*—The deposits of lead- and zinc-ores of the Ozark and Wisconsin uplifts do not occur invariably in the form of runs. In

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* *Report on the Quicksilver Deposits on the Pacific Slope.*

† Paper read before St. Louis Academy of Science, April, 1890.

a few instances noted in Jasper and Newton counties, Missouri, fissures traverse the Cherokee limestone without disturbing the stratification, so that in the deposition of the ores, the solutions unable to escape from the fissures and penetrate the wall-rock, deposited the ores in the breccia included between the walls, forming ore-bodies which are vertical, tabular sheets of ore, closely resembling in structure the ore-shoots of fissure-veins. Near Dubuque, Iowa, lead-ores occur in vertical sheets, often of large size, deposited within the eroded walls of the crevices ; smaller bodies of galena, in like manner included within the fissures, are found in many localities in the Wisconsin region. These occurrences indicate the close relationship of runs to the fissure-veins, and show that the form of the ore-bodies has resulted from the composition and structural condition of the wall-rock. Where the ascending solutions could escape from the fissures and penetrate the beds, owing to the permeability of the rocks or to their fracture or brecciation, runs have been formed ; and where the wall-rocks have been impervious, and therefore have confined the solutions within the fissures, the ore-deposits are in shoots.

The fact that in runs the ore is confined in vertical extension to the thickness of the ore-horizon cannot be regarded as a specific difference, for in fissure-veins the ore-shoots are often strongly influenced in occurrence and in location by the character of the wall-rocks, and many instances are seen in the mining-regions of both America and Europe where fissure-veins become barren in passing from one geological horizon to another, and are productive only where traversing certain strata.

*Occurrence of Runs in the West.*—The occurrence of ore-deposits in favorable horizons and in the form of runs is not confined to the Ozark and Wisconsin areas, but has been observed by the writer in many mining-districts in the West, in localities where the sedimentary rocks are substantially horizontal, and are traversed by vertical faulting fissures affording the channels for the introduction of the ores. The occurrence of runs in the Potsdam sandstone of the Black Hills, South Dakota, may be noted, where they are formed by the intersection of certain calcareous or shaly beds, which constitute the favorable horizons, by vertical faulting fissures. In this mining region the runs carry argentiferous galena in the Bear Butte district, while in the neighboring district of Bald Mountain, over a broad area and in the same Potsdam formation, extensive and richly-impregnated beds or runs of refractory gold-ore are mined. Large compound runs of argentiferous lead-ore are found in the Carboniferous

limestone at Horseshoe Gulch, near Leadville, Colorado, and the recently discovered mines of silver-bearing galena near Good Springs, Lincoln county, Nevada, similarly occur in runs or impregnated beds in limestone of Carboniferous age.

The ore-deposits of the Ozark and Wisconsin uplifts, with all the multiform local variations, may be classed under two generic forms: deposits filling enlarged sections of the crevices; and impregnations extending outside of the fissures which introduced the mineralizing solutions. These forms are all included under the designation of runs, adopted from the miners of the Southwest.

In conclusion, no good reason appears for placing these ore-deposits in a separate class from fissure-veins because of distinctions based upon the form and position of the ore-bodies relative to fissures. On the contrary, these runs, considered in connection with the fissures through which they were formed, belong to the great class of ore-deposits in which the origin of the ore is in mineral-bearing solutions, ascending through the fissures from some source of unknown depth in the crust of the earth, of which class fissure-veins are the simplest typical form.

*Time at which the Formation of the Ore-Deposits Occurred.*—All the deposits of zinc- and lead-ores of the Mississippi valley appear to have been formed at the same period of time, without respect to the age of the geological formations in which they occur. Though the time at which the deposition of the ores took place cannot be definitely fixed, we are not without evidence bearing upon the question. The ore-forming period was certainly subsequent to the Carboniferous, as the ore-bodies in the Cherokee limestone extend up into the overlying shales of the Coal-Measures. Further, a great length of time was expended in effecting the subterranean erosion of the limestones that antedated the ore-forming period; a work accomplished by the slow solvent action of percolating surface-waters, and one that could commence only when the region became dry land at the opening of the Carboniferous.

Boulders of float-galena derived from the ore-deposits have been found in the Drift in Iowa* and in Pliocene gravels along the Mississippi river near the mouth of the Ohio;† water-worn fragments of chert carrying galena, occur in the Orange sands near Helena, Arkansas, regarded as pre-Pleistocene in age.‡ Fossil bones and teeth of the mastodon, megalonyx, and an extinct species of peccary

* White. † McGee. ‡ Branner.

have been discovered in the upper parts of lead-bearing crevices in Wisconsin.* These and other evidences obtained in the course of this investigation make it probable that the primary deposition of the ores had terminated before the later Tertiary. Since the close of the period of deposition, the ores near the surface have been oxidized by atmospheric agencies to a depth locally as great as 100 feet. Caves, many of which are of great extent, have been formed in the limestone by the action of surface-water, and the larger streams draining the mining regions have deepened their beds from 50 to 100 feet.

Between these shores of time, the epoch of the Coal-Measures and the Pliocene, the formation of the ore-deposits in all probability occurred. No ores are now being deposited in the strata, and conditions other than those at present existing must have prevailed in the ore-forming period. That the deposition was the result of dynamic action deeply located in the crust of the earth, follows from the connection of the ore-deposits with faulting fissures, and the acceptance of a source of the metals in depth.

The only epoch in Mesozoic or Cenozoic time known to have been characterized by other than local dynamic action in the Mississippi region, is that which begins with the continental disturbances at the close of the Cretaceous and continues to the later Tertiary,—a period distinguished by intense dynamic action which extended its effects over the western half of the North American continent, and was signalized in many widely separated regions by great outbursts of eruptive rocks.

In the Ouachita uplifts the eruptive intrusions are post-Cretaceous.† The outbursts of trap and basalt in Indian Territory and Texas are of the same age.‡ The Ouachita and Ozark uplifts are closely contiguous, the narrow valley of the Arkansas river marking the separation; and while they differ radically in formation and structure, these insular areas are intimately related with respect to the dynamic events that have taken place in their geologic history. The extensive igneous disturbances of the Ouachita uplift were presumably connected with the formation of the veins of argentiferous lead- and zinc-ores; analogy would imply that the ores of lead and zinc of the Ozark region were probably deposited at the same period.

The epoch of the formation of the argentiferous ores of the Rocky

* Whitney. † Branner. ‡ Hill.

Mountains was inaugurated by the disturbances at the termination of the Cretaceous period and continued through the Tertiary.* The silver- and lead-deposits of the Black Hills of Dakota were determined by the writer to have been formed at this same period and to have resulted from igneous action connected with the extravasation of the eruptive rocks. A parallel has been drawn between the early geologic history of these areas of uplift in the Mississippi valley and that of the outlying elevations along the eastern slope of the Rocky Mountains. A similar uniformity can be traced in these far separated mining regions with respect to the dynamic disturbances that have taken place, and the formation of the mineral deposits.

In conclusion, all evidences point to the deposition of the lead- and zinc-ores of the Mississippi valley as the result of disturbances which, while local in their action, were connected with the widespread disturbances, accompanied by intrusions of igneous rock and the formation of mineral-deposits, that in post-Cretaceous and Tertiary time extended over the Rocky Mountain system from Mexico to British America.

## Discussion of the Theories of Ore-Deposition.

The absence of all igneous rocks and all evidences of igneous action in the ore-bearing formations of the southern Missouri and the Wisconsin-Iowa mining regions, renders it unnecessary to consider any theory in explanation of the deposition of the lead- and zinc-ores, based upon igneous injection or sublimation of the metals. The discussion may therefore be confined to the theory of ascension, or deposition of the minerals from solutions rising from unknown sources in depth, and of lateral secretion, or the deposition resulting from the concentration, in the crevices, openings and favorable beds, of the minute particles of the metals originally disseminated throughout the inclosing strata. In this discussion, the term lateral secretion is used in a somewhat restricted sense, to mean that the ores have been derived from minute disseminated particles of lead, zinc, iron and copper, primarily deposited in the inclosing sedimentary rocks, or in the beds overlying or underlying the ore-horizons; and that by a process of segregation through the medium of the subterranean circulation of atmospheric waters, they have been leached from the strata and concentrated in the crevices and fissures in which they are now found.

* Clarence King.

This theory of lateral secretion was advanced by Whitney in *The Metallic Wealth of the United States,* published in 1854, and subsequently in more detail, in his Report on the Upper Mississippi lead-region. Whitney expressed the opinion, from his investigations of the Wisconsin-Iowa lead-region, that the crevices now filled with ores of lead and zinc, originated through the action of local causes, or of forces limited in operation to a comparatively narrow vertical range, and to rocks of similar lithological character; and that the origin or source of the metals was in the Trenton and Galena limestones. He regarded it as improbable that the ores resulted through deposition from solutions ascending from the deep-seated Archæan rocks, and in summing up the discussion of the origin of the ore-deposits, he says: "In view of all these facts we consider it as a matter settled beyond all possibility of doubt that the lead-deposits of the Northwest must have been introduced from the fissures from above, and by precipitation from a solution."* The results of the present investigation have led to a different conclusion, not only as to the origin of the metals, but also as to the manner of formation of the ore-deposits. This conclusion is supported by many minor details in the occurrence of the ore-deposits and the associated fissures that cannot be set forth in this brief paper.

The strongest argument in favor of the mode of deposition from solutions rising from unknown sources in the crust of the earth, is that the ore-bodies are associated with faulting-fissures of indefinite extension in depth, and that all the evidences of the occurrence of the ores and minerals in the deposits point to these fissures as the channels through which the mineralizing solutions were introduced. The localization of the ore-deposits is difficult of explanation by any theory of lateral secretion. The Cherokee limestone extends over an area of 4000 square miles in the Southwest, yet it is everywhere barren except in the mining-districts dotted over the region. The Magnesian limestones cover one-third of the area of the State of Missouri, but carry ores in districts of limited extent distributed without regularity, while great tracts of these limestones are unmineralized. These Silurian limestones are exposed over large sections of the Mississippi valley, but are ore-bearing in only a few localities. If the minerals and ores in these formations were deposited by lateral secretion, it is not easy to understand why the ores do not occur more generally distributed. The true explana-

* *Report of a Geological Survey of the Upper Mississippi Lead Region,* by J. D. Whitney, 1862, p. 398.

tion is, that these local areas are mineralized because they are centers of disturbance and faulting of the strata, and the surrounding territory is barren because of the absence of any dynamic action that has been capable of forming fissures extending to the deep, whereby the ore-depositing solutions could gain access to the strata.

The minerals that form the ores and the gangue are not such as would be predicated, were the metals derived from the inclosing strata. Had the lead and zinc been segregated from the limestones in which the ore-deposits are found, it would be natural to expect that the prevailing gangue of the ores would be calcite; but this mineral occurs in relatively small proportion in the ore-bodies and is always of secondary deposition, overlaying the primary ores. Dolomite is a very rare mineral in the ore-deposits in the Galena limestone in Wisconsin, although that formation is highly magnesian in composition. On the other hand, vast masses of dolomite form the gangue of the ore-bodies in the Cherokee limestone in the Southwest; yet analysis shows only traces of magnesia in the limestone itself.

Neither will any theory of lateral segregation explain the paragenesis of the minerals in the Cherokee limestone; or how it happens, when the conditions are apparently identical in the same horizon, that one or more of the primary elements, dolomite, blende, galena or cherokite, may be absent in an ore-body, though abundant in the mines in the vicinity; or the occurrence of deposits of blende free from galena, and of corresponding mines of galena without even traces of zinc-ore, and of ore-bodies formed of these minerals intermingled, all occurring under apparently identical conditions and in rocks of the same lithological character. If the deposition of these minerals is assumed to have been effected by successive upflows through the fissures, from some source in depth, of solutions of different chemical composition, it is easy to understand the uniform order of formation throughout the region; while the absence in certain mines of one or more of these primary minerals, may be explained by variations in the mineral contents of the solutions in different localities, or by the temporary suspension of the mineralization from some cause.

The examination of the Cherokee limestone, which is the principal ore-producing formation of the Mississippi valley, affords no evidence that the ore-deposits have been derived from that horizon, or from the sedimentary rocks situated above or below it in the geological column. The traces of lead and zinc detected by an analysis

of the unaltered Cherokee limestone, are entirely inadequate (were it possible to conceive of a perfect concentration of the disseminated metals in the rocks from miles on every side of the mining districts) to form the large ore-bodies that are grouped together.

It is reasonable to suppose that the solutions resulting from lateral secretion would be weak and would deposit their metals slowly, but this does not correspond with the occurrence of the ores in a number of the mines in the southwest, where the small size and crowded growth of the crystals indicate a rapid deposition from concentrated solutions. Lateral secretion, if it takes place at all, is in all probability confined to the zone of oxidation; and by the general topography of the mining regions, this zone is limited to a depth of 100 feet from the surface, and averages less than 50 feet. The minute traces of lead and zinc disseminated through the sedimentary rocks probably exist as sulphides, and in this form they are insoluble and permanent in ordinary subterranean waters, unless they become oxidized and decomposed—an action that is confined to the zone of oxidation near the surface.

The perfect faces and sharp edges of crystals of blende and galena, lining the water-channels in the lower parts of the ore-bodies, show that, below the zone of oxidation, no solution or decomposition of the metallic sulphides takes place. Even where the lead and zinc become oxidized and pass into solution in the circulating waters, contact with the organic matter contained in the rocks in the presence of alkaline sulphates, which occur in all mineral waters, immediately reduces and precipitates the metals as sulphides.

$$PbO,CO_2 + CaO,SO_3 + H_2O + 2C = PbS + CaO,CO_2 + 2CO_2 + H_2O.$$

It is this protective action of the organic matter disseminated through the strata, that has limited the zone of oxidation to so shallow a depth in the mining-regions; for until all the carbon contained in the rocks is first consumed by oxidation, no decomposition of the minerals can occur or any segregation of the metals take place. There is nothing to warrant the belief that the normal underground circulation of waters will effect the extraction and segregation of the ores disseminated through the rocks below the zone of oxidation; and while it is probable that by some process of lateral secretion, the galena and blende which are occasionally found in small quantities, crystallized in the interior of geodes, or filling the cavities in fossil shells, are derived from adjacent strata, no action of this

nature is adequate to form the immense ore-deposits of the Mississippi valley.

The deposition of the ores has long ceased; no ores of lead or zinc are now being formed, other than by secondary deposition resulting from the decomposition of the primary ores, and it has been shown that the ore-deposits were formed probably in post-Cretaceous and Tertiary time, certainly later than the Coal-period. To account for a deposition of the ores by lateral secretion at a definite period of time, and not in the ages prior or subsequent to the Tertiary, although the country has been continuously dry land from the beginning of the Carboniferous to the present, it would be necessary to assume that the conditions under which the segregation of the metals took place were not only substantially different from those now subsisting, but were different from those occurring in the interval between the termination of the Subcarboniferous and the close of the Cretaceous. Nothing, however, appears to warrant the assumption that, in the ore-forming period, the prevailing conditions of climate were such as to give the circulating sub-äerial waters a different chemical composition, or increased solvent power, or a temperature or pressure greater than that of the subterranean waters of the present time.

*Conclusion.*—The burden of proof is upon the advocates of the theory of lateral secretion; for the mineral-deposits of the Appalachian and the Rocky Mountains, of the Lake Superior region and of southwestern Arkansas, that surround on all sides the lead- and zinc-mining regions of the Mississippi valley, are all formed by ascension. The peculiar occurrence of the ore-deposits in the form of runs, is characteristic as well of certain mining-districts in the West as of the Ozark and Wisconsin uplifts; of mines of lead, silver and gold that are unquestionably formed by ascension and not by lateral secretion.

The only theory which, in all observed instances, will account for the occurrence of the deposits of lead- and zinc-ores and the associated minerals in the Upper and Lower Mississippi region is that of ascension, the source of the metals existing deep in the primitive rocks. With the discovery that the ore-bearing crevices are faulting-planes of indefinite vertical extension, the classification of the deposits of the Mississippi valley as the fillings of "gash-veins," or crevices formed by the contraction or shrinkage of the rocks, and confined to a narrow vertical range within the geological horizon, must be abandoned.

## Rules for Prospecting.

As one result of this investigation, the following rules may be laid down for the guidance of the miner :

I.—The old rule "*to follow the ore,*" holds good in this as in other mining-regions, but cases arise where other guides must be sought; as where the ore-body is worked out and search is made for other deposits in the vicinity; and in the prospecting of virgin ground and the exploiting of areas but little developed.

II.—In all underground prospecting the general rule may be given, *to follow the more prominent vertical fissures in the search for ore;* for these have been the channels through which the solutions have entered the rocks and formed the ore-bodies, and along the course of which, in favorable ground, the deposits of ore occur.

III.—In prospecting new ground, attention should be given to the indication of the course of the fissures and cross-fissures; *the work should be concentrated upon the areas of crossing or intersection of the different belts of fissures;* for experience has shown that the largest ore-bodies are situated at such crossings of different fissure-systems. On the surface the course of the fissures may be traced in some localities by the direction of low bluffs or breaks, or by sags or lines of depression in the even contour of the topography; also by the strike of outcrops of silicified rock, more or less mineralized and stained with iron. When carefully searched, such outcrops often afford traces of the oxidized minerals resulting from the weathering of galena and blende. Evidences of the disturbances of the rocks should be carefully observed; such as, beds dipping locally at steep angles, or in a direction different from that of the prevailing inclination of the strata in the region; and the occurrence of belts of folded, crushed or brecciated rocks. The character of the vegetation upon the surface is usually an uncertain guide in prospecting; in rare instances, the course of an ore-bearing crevice is marked by a narrow belt which is destitute of vegetation on account of the poisonous action of the salts produced by the decomposition of the minerals. Underground, the course of the fissures, not only in the mine but in all workings of the vicinity, should be carefully surveyed and platted. The probable intersection of the different fissures may be determined by prolonging on the map their surveyed courses both underground and on the surface.

IV.—An advisory rule may be given, *never to sink a shaft without having put down a drill-hole,* in order to ascertain the character of

the underlying formations, lest time and money be wasted from striking hard and massive strata, or areas of barren rock. In the future, prospecting drills, such as are commonly used in sinking artesian wells, will be more generally employed in the search for ore. The diamond-drill is not adapted for this work in prospecting in the Cherokee formation, on account of the loose and open structure of the ground and because the hard chert cuts out the diamonds. In the Cambrian limestone the massive and uniform structure of the beds and the absence of chert are favorable for the successful employment of the diamond-drill.